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The SOLAR HOT WATER Handbook

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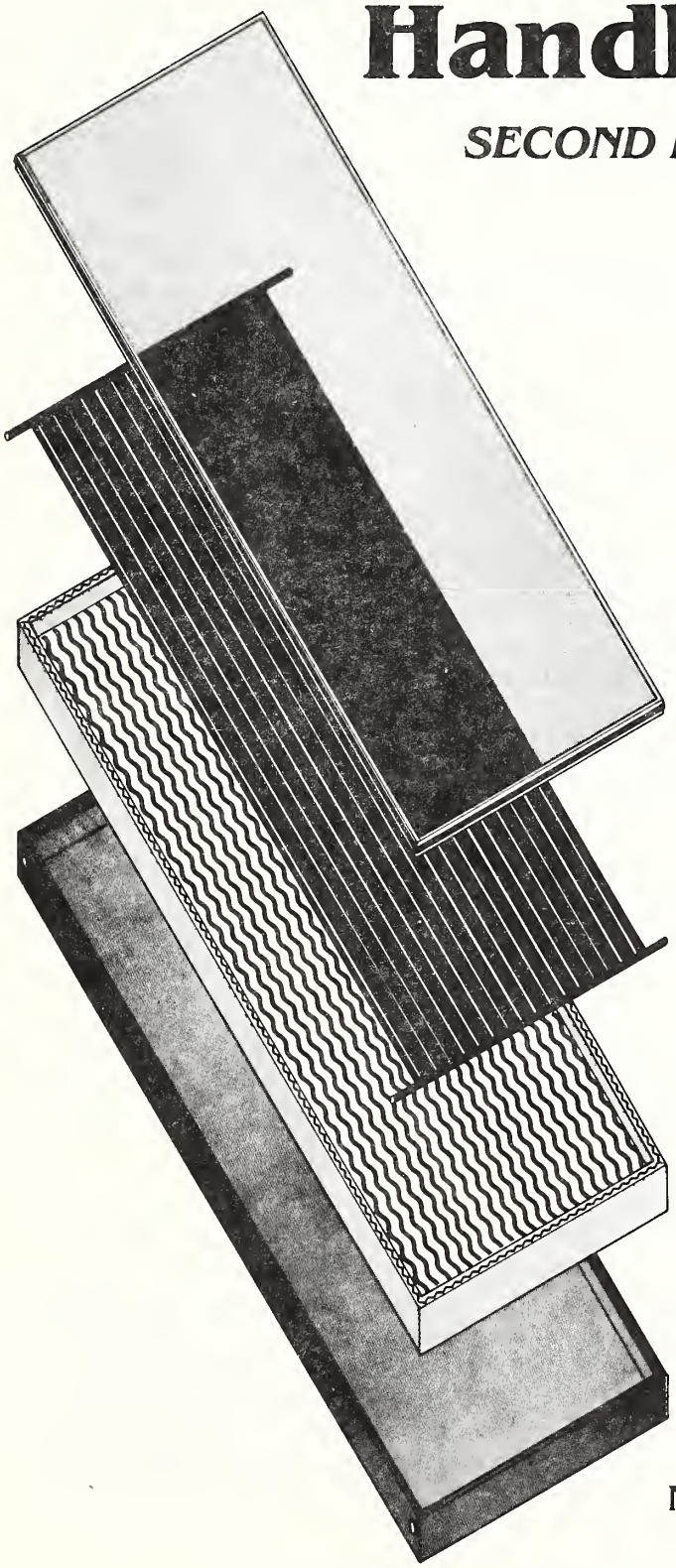
The SOLAR HOT WATER Handbook

SECOND EDITION



Edited by

James Kirby

and Leslie Hill

Reprinted and Distributed by
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Specified material from "Installer/Inspection Qualification Workbook on Renewable Resources," by Solar Energy Resource Institute, 1982, appears throughout the text.

"Design Note 1: The Collector Efficiency Curve," by William Wright, and "Design Note 2: What is f-Chart?" by Ross Bisplinghoff, were reprinted from the Northeast Solar Energy Center Solar Design Series.

"Troubleshooting Guidelines" were reprinted from the Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, Argonne National Laboratory: ANL/SDP-9; Solar/0907-80/70.

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There is a continuing need to train qualified solar installers who can join the workforce. In order to do this, accurate and up-to-date general information which covers various types of solar equipment is necessary. This book provides an overview for installers who are entering the solar installation business or for tradespeople in other related fields who want to understand different approaches to solar domestic hot water. It has been structured so its contents can be covered in a two-to-three day workshop.

The detailed reference charts that have been included extend the life of this publication beyond the training period so that it can continue to be useful as an installer's handbook. The information provided herein is no substitute for specific product installation guidelines and does not reduce the manufacturer's responsibility to include a training manual with solar equipment.

The History of this Publication

In 1977, the federal government began writing *Installation Guidelines for Solar DHW Systems,* which came to be fondly referred to as, "The HUD Manual." The procedures in it complied with HUD's *Intermediate Minimum Property Standards Supplement, Solar Heating and Domestic Hot Water Systems* and with most national building codes. The information in it was composed primarily from manufacturers' product literature.

Further federal support for the solar industry came when the regional grantee, Northeast Solar Energy Center (NESEC) sponsored installer training programs in six New England states and Canada from 1979–1981. The trainers for the NESEC program were all members of The National Association of Solar Contractors (NASC) which continued the statewide installation training programs in the northeast after the funding from NESEC ceased.

It was members of NASC who, determined to update The HUD Manual, wrote the first edition of this book for their workshops. Although NASC is now currently inactive, the individuals who contributed to this revised edition still promote high standards for installing solar equipment. *The Solar Hot Water Handbook* has been revised and updated in 1984 specifically for a statewide training program which is being sponsored by the State of Montana. It is the hope of the editors that this new edition will inspire qualified trainers and help facilitate other solar training workshops.

Leslie Hill and James Kirby
April, 1984

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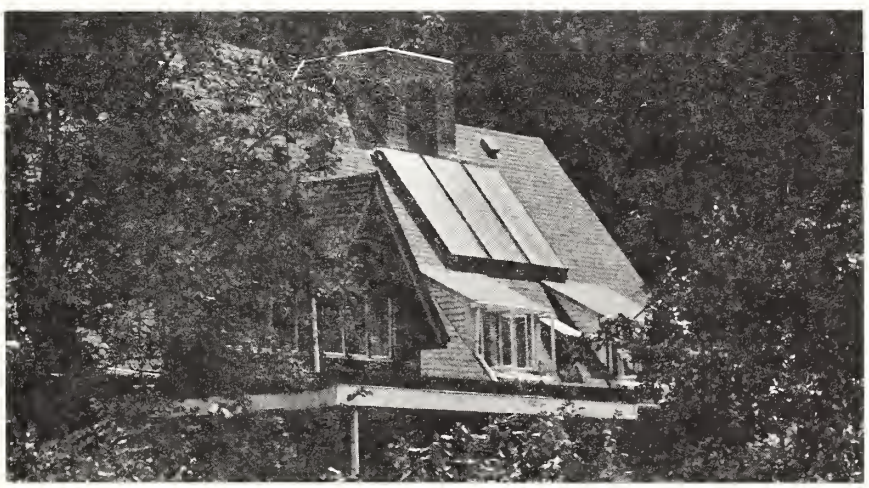
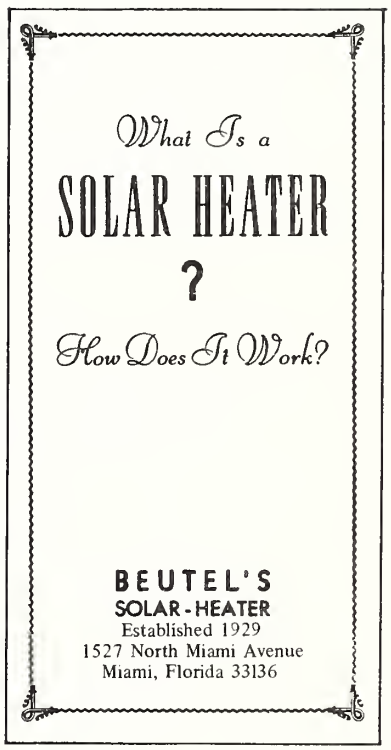
CHAPTER ONE

System Types

There are eight major types of solar domestic hot water systems. These are examples of the "generic types."

- ***Closed loop antifreeze with internal heat exchanger***
- ***Closed loop antifreeze with external heat exchanger***
- ***Drainback with an unpressurized reservoir***
- ***Draindown with solenoid valves***
- ***Thermosiphon with storage tank above collectors***
- ***Phase change with refrigerant fluid***
- ***Air-to-Water***
- ***Batch***

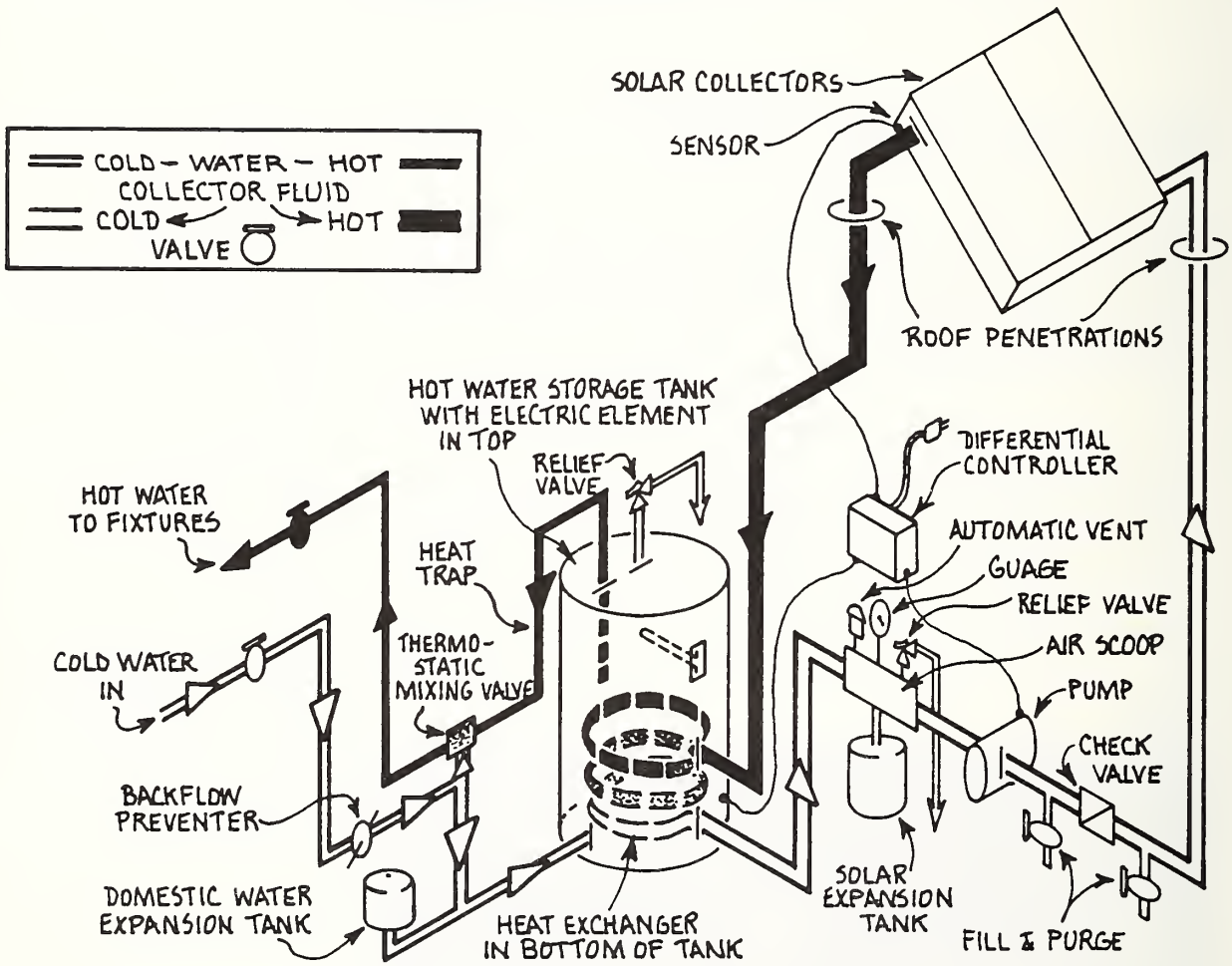




CLOSED LOOP ANTIFREEZE WITH AN INTERNAL HEAT EXCHANGER

These systems are comprised of a tank with an internal heat exchanger, a pump/control package, piping and collectors, and an anti-freeze mixture (usually water/glycol or some other freeze resistant fluid). The fluid transfers heat from the collectors to the heat exchanger in the tank.

A conventional pressurized storage tank is used. It is similar to an electric water heater tank except that it has a heat exchange coil in the bottom. An electric heating element is frequently installed in the upper level of the tank to provide auxiliary heating. Usually, closed loop anti-freeze systems are installed with a single tank which combines electric back-up with solar heating. However, they can be also installed with a second conventional electric tank, a furnace or a wood stove.

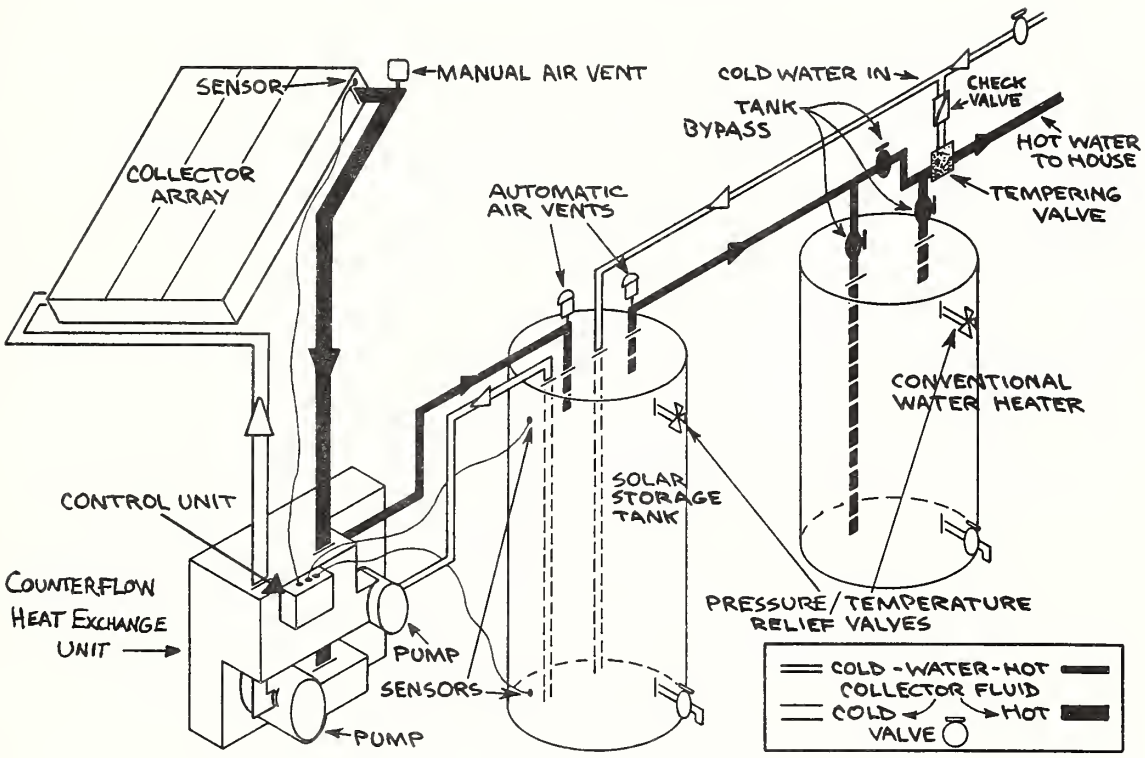


CLOSED LOOP ANTI-FREEZE WITH A COUNTER FLOW HEAT EXCHANGER

This system requires two loops. One loop runs between the external heat exchanger and the collectors and the other runs between the external heat exchanger and the tank. The con-

troller operates two pumps which circulate fluid in each loop using a counter flow pattern. Counter flow heat exchangers offer very high heat transfer. A pressurized tank is used for solar storage. It can be either glass or stone lined. A second tank, which is one-third to one-half the size of the solar tank is used for conventional back-up energy.

While this system offers higher heat exchange efficiencies, it has higher heat loss and pumping costs than single tank systems.



DRAINBACK WITH AN UNPRESSURIZED TANK

Drainback systems pump water up to the collectors and use gravity to drain the water back down to an unpressurized tank. While the pump is running, there is fluid in the collectors: when the pump turns off, the system drains. The high-head, low-flow pumps are more powerful than closed-loop-type circulator pumps, because they must be able to pump water UP to the collectors each time the system turns on.

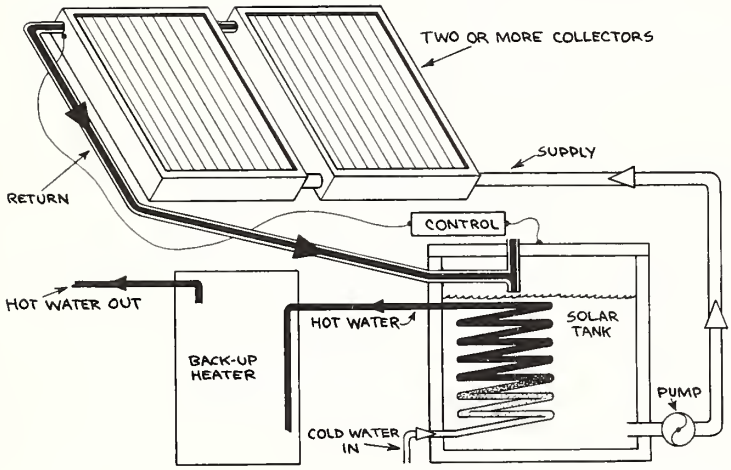
Collectors and piping must be pitched so that ALL the water will drain. The collected thermal energy is transfered to domestic water by either an "active" or "passive/convective" approach.

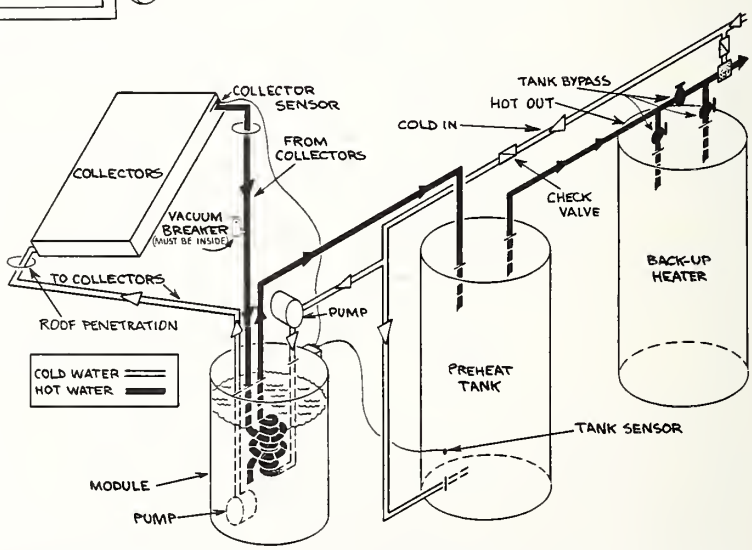
Passive/Convective System

A large volume coil or tank is placed inside a larger unpressurized tank. As domestic water is used, fresh water is drawn through the coil to the conventional water heater, and is passively pre-heated as it flows through the immersed tank.

Active/Module System

A counterflow pipe-in-pipe heat exchanger is immersed in a small unpressurized tank. The solar side of the exchanger is open to the container. After the fluid has moved through the exchanger, it flows out into the tank to be pumped up to the collectors. The domestic side of the heat exchanger is connected to a small bronze or stainless steel pump and a glass or stone





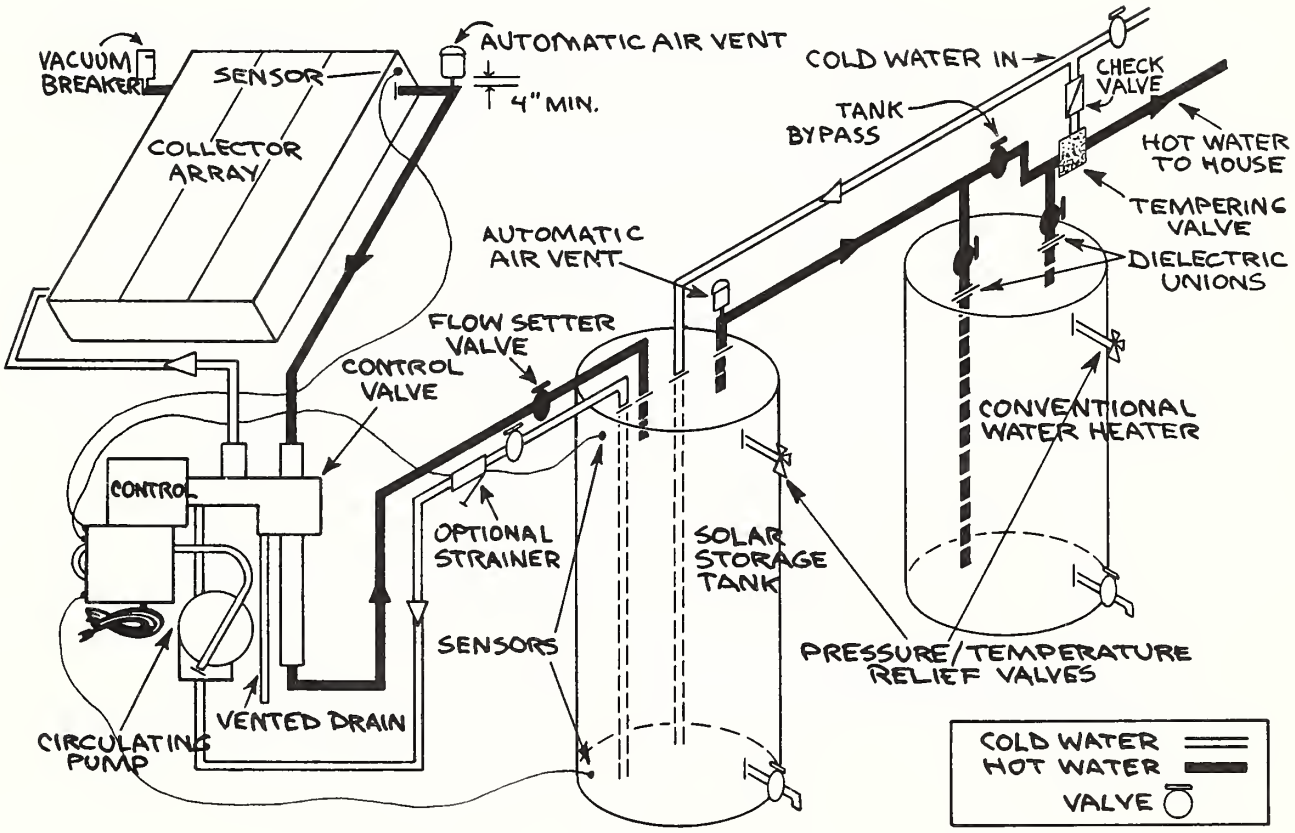
lined pressurized tank. Since the solar storage tank is pumped continuously during periods of collection, a second tank is needed to provide conventional back up. This is necessary because collector efficiency will be affected adversely if the solar storage is heated conventionally.

DRAINDOWN

Draindown systems use electrically operated solenoid or "spool" valves to allow pressurized domestic water to be circu-

lated directly through the collectors. When the collectors become warmer than storage, the solenoid valve opens, thus filling the solar loop with domestic water. A bronze or stainless steel pump circulates water through the collectors.

When the temperature in the collectors approaches that in the tank, or when a "freeze sensor" signals for a drain cycle, the valves close and the pump turns off. The water in the collectors and solar loop flows by gravity to a drain emptying the loop. Since the valves are normally-open, a power failure will signal a drain cycle and prevent damage to the system. Usually an additional tank is needed for back up heating.

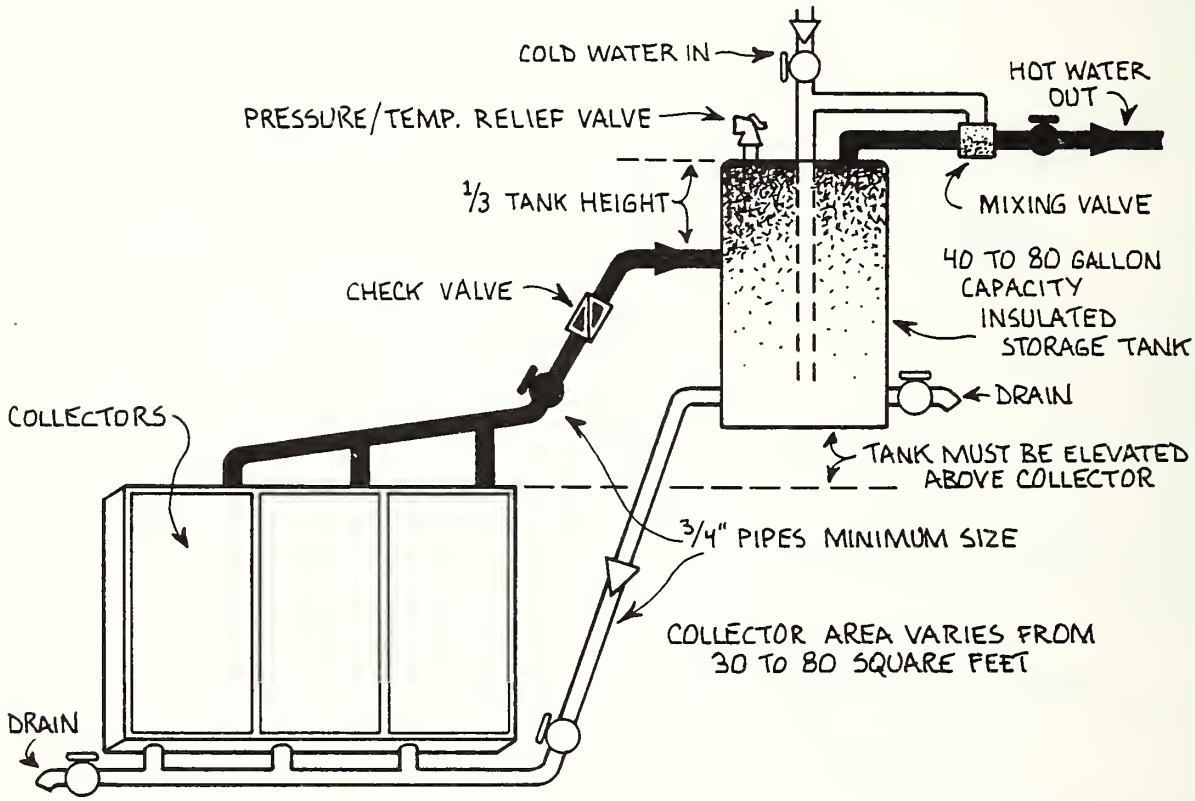


THERMOSIPHON SYSTEM

Thermosiphon systems are passive systems which operate on the principle of natural convection. The natural rising of heat causes the warmer fluid to flow into the storage tank which is located above the collectors. Hot water is then drawn from the tank. In the first half of the twentieth century many homes in

southern California and Florida had thermosiphon systems to heat their water.

The technology dwindled only when other energy sources became less expensive and more readily available. The system is designed for simplicity, dependability, and economy. It is passive and requires no pumps or controllers. Since the system will thermosiphon in both directions, a check valve is always located in the system to prevent reverse thermosiphoning. However, there is always the danger of unexpected freezing weather in warm regions and then the system has to be manually drained.



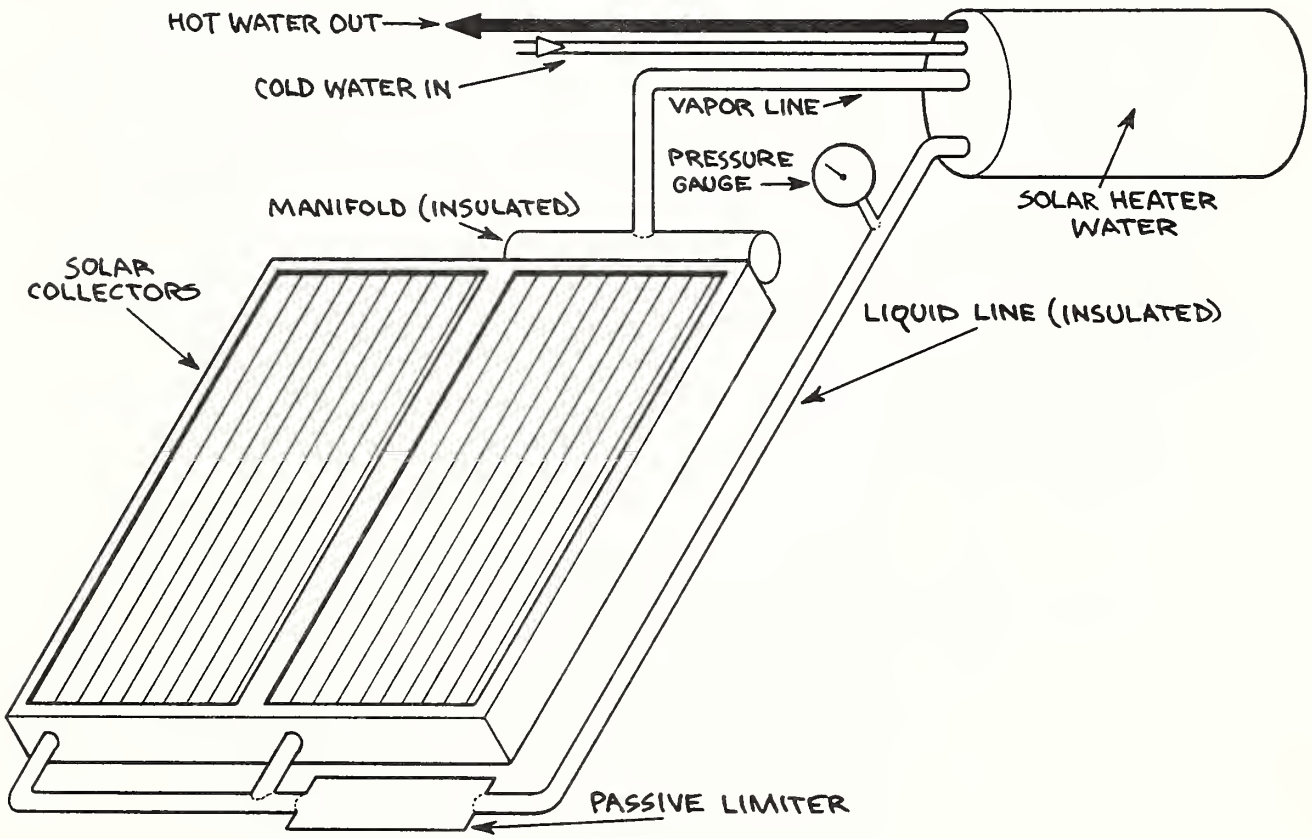
PHASE CHANGE SYSTEMS

These systems use refrigerant as the heat transfer fluid. Refrigerants are inert so corrosion does not occur in the solar loop. Because the refrigerant turns from liquid to vapor in the collector when the sun is shining, the collector "runs cool" and offers more efficient heat removal. Phase change systems can use pumps or thermosiphon.

There are pumps and valves designed specifically for refrigerant charged systems. If the tank can be installed above the

collectors and if the piping can be installed in a sloping upward path, with no isolated high points, then a thermosiphon design can be used.

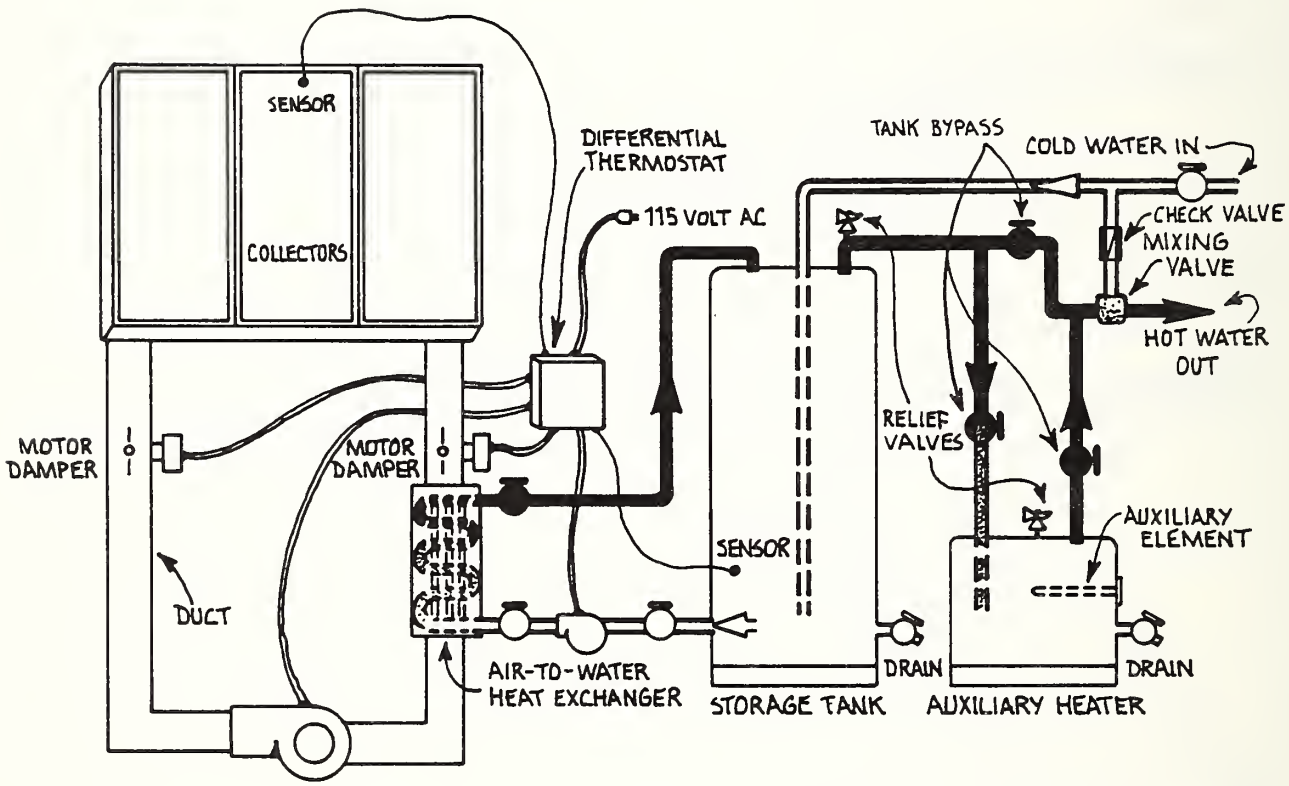
When the sun heats the collectors, the liquid refrigerant is vaporized. It rises and is carried to the heat exchanger located in the water tank (positioned above the collectors). Condensation occurs and the latent heat of the refrigerant heats the water. The liquid refrigerant then flows by gravity to the bottom of the collectors, completing the cycle. The temperature of the water in the tank determines the system pressure. Because the refrigerant loop always contains both liquid and vapor phases, separated by gravity, reverse heat flow is not possible. When hot water is drawn, pressure in the system decreases and the valve opens.



There are several methods of limiting tank overheating. Higher pressure will turn the system "off," or pressure activated valves may be used.

AIR

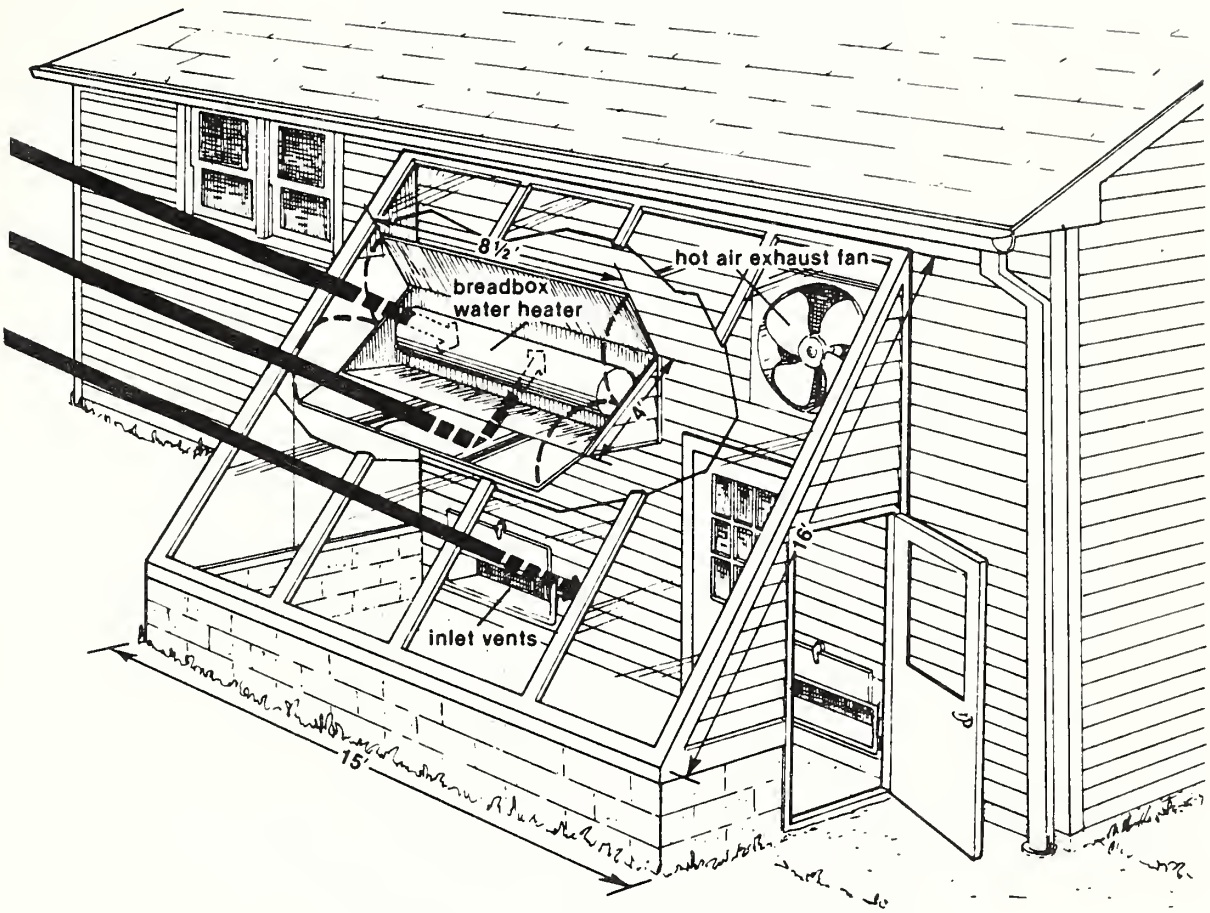
In air systems, hot air generated by the collectors is fan-forced through an air-to-liquid heat exchanger, with the potable water pumped through the liquid section of the exchanger. The heated water is then circulated through the storage tank just as it is from the tank in a closed loop antifreeze system with a counter-flow heat exchanger. Air does not freeze or boil and is non-corrosive. However, air-to-water heat exchangers can freeze, and backdraft dampers must be installed to prevent reverse thermosiphoning. Air ducts require greater space than piping and must be installed carefully to prevent air leaks. Air handling equipment has higher operational costs.



BATCH

Batch systems use a storage tank that is directly exposed to the sun. The tank is not insulated. It is painted with flat black paint or with a selective surface. Batch systems are usually double

glazed, but sometimes there are additional layers of a film glazing. The rear surfaces are often covered with a reflective surface which helps direct more sunlight on to the tank. Many batch heaters have insulated covers which can be closed at night to further lower heat loss.



Batch systems should be located as close as possible to conventional water heaters to avoid heat loss in long pipe runs. If batches are located a long way from the conventional water heater, a substantial amount of the heat collected by the batch will be lost in the piping. The performance of batch heaters can be significantly improved by adjusting hot water consumption to the availability of solar hot water.

OTHER SYSTEMS

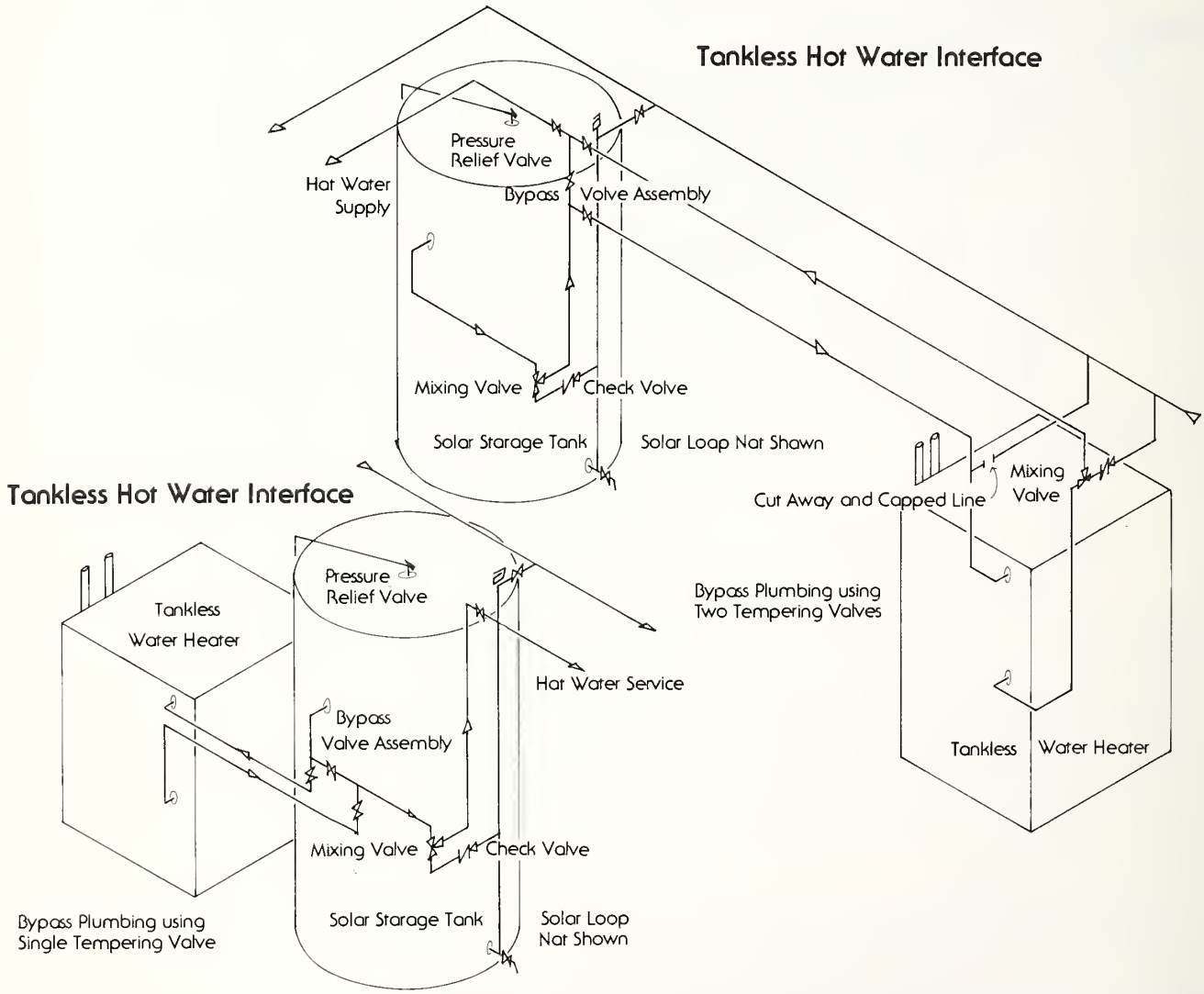
A number of system types are found only in limited areas or in custom-designed projects. Manual draindown systems use potable water for the heat transfer fluid without any antifreeze additives. The owner has to operate the draindown valve manually. These systems can be operated only in regions or during seasons where there is little chance of freezing weather.

Reverse-trickle, or pulse-circulation systems pump a quantity of hot water from the storage tank into the collector array, lowering system efficiency when there is danger of a freeze. This type of system is very popular in Florida and Southern California.

There are also draindown systems which use air pressure in the storage tank or in a separate pressure tank to force water out of the collectors when a freeze threatens.

FURNACE AND TANK BYPASS

In order to supplement water demands which are not met by solar systems, many systems are installed in conjunction with conventional water heaters, furnaces, or boilers which are fueled by gas, oil, wood, coal or electricity. The conventional systems can be bypassed entirely during periods when they are unnecessary, and then reactivated during periods when the solar installation cannot supply the full energy load.



This is done by installing a tank bypass with three ball shutoff valves. Ball valves are recommended because they are easiest for the homeowner to change from summer to winter.

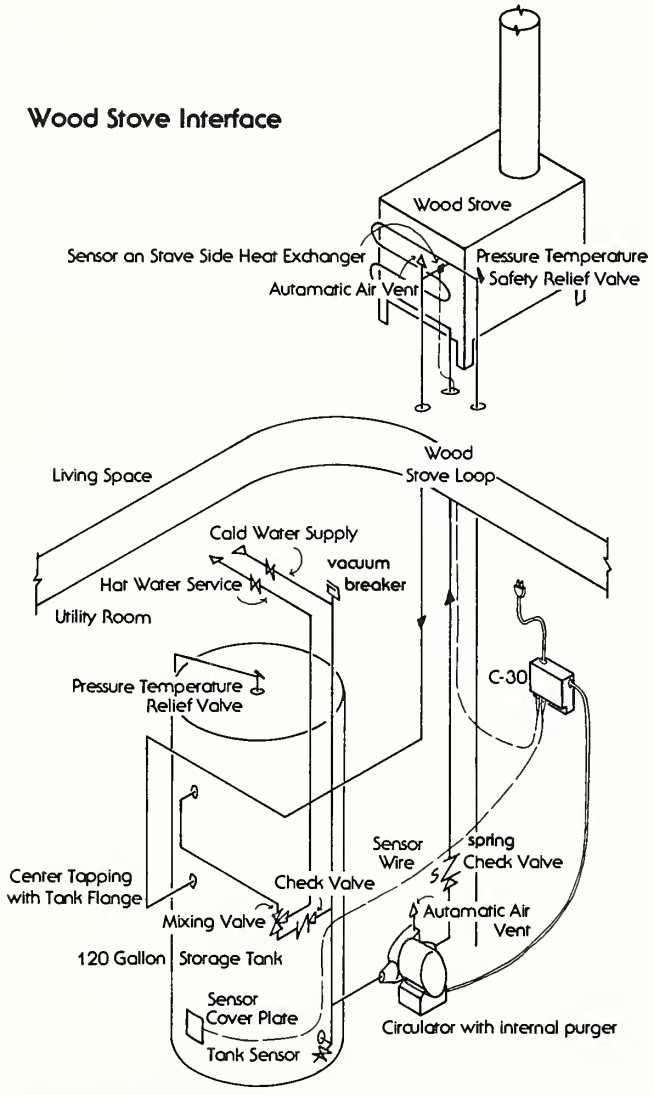
THREE VALVE SEASONAL BYPASS POSITIONS

VALVE	SUMMER	WINTER
By-pass	Open	Closed
To Conventional Tank/Furnace	Closed	Open
From Conventional Tank/Furnace	Closed	Open

Note: *Because conventional systems can be bypassed during the summer, it is necessary to have a pressure relief valve on the solar storage tank as well as on the conventional tank/furnace.*

WOOD STOVE INTERFACE

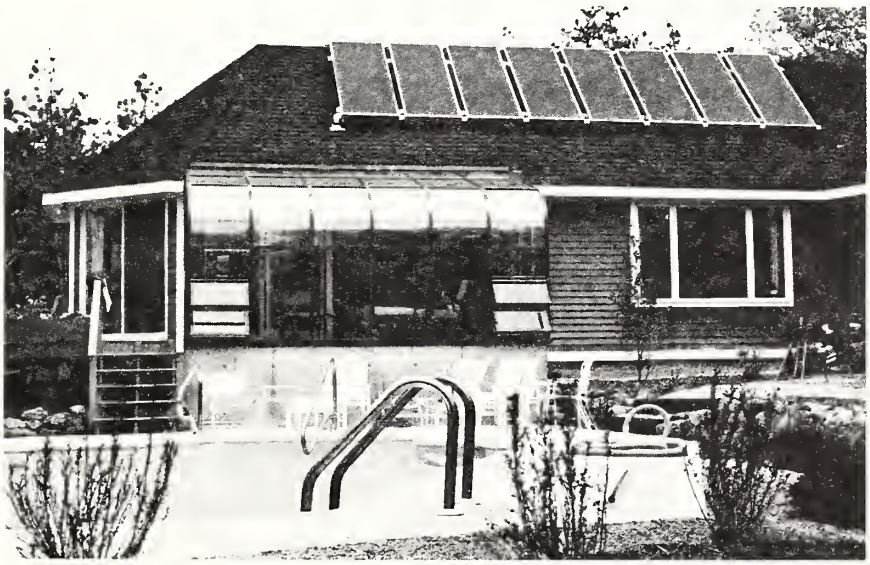
Wood stoves, furnaces and boilers have become popular sources of back-up heating for solar domestic hot water systems. Coils are installed either inside or outside the fire box. Fluid can be circulated by pump or thermosiphoning. It is important to install separate pressure relief valves that can not be isolated from the wood stove. The pump can be controlled by either set-point controls or a differential controller.



Solar Collectors

The function of a solar collector is to capture and convert sunshine into usable heat. Manufacturers make many different models which fall into three groups distinguished on the basis of heat output. System designers need different collectors for different applications.

Low Temperature Applications
Solar pool heating systems should heat pools to between 70°F and 85°F. These systems often use unglazed collectors.



Intermediate Temperature Applications
Solar Domestic Hot Water Systems should heat water to between 110°F and 140°F. These systems often use single glazed flat plate collectors. Their absorbers may have a flat black finish or a selective surface.

High Temperature Applications

Solar-powered air conditioning or high temperature process heat applications must heat fluids to temperatures above 180°F. These systems often use concentrating or evacuated tube collectors.

DESIGN

Absorptance

The goal of the collector designer is to select design features which improve the conversion of light energy to heat energy and/or to reduce heat loss from the collector. Design considerations include glazing, insulation, absorber surface, mirrors, vacuums, case and mounting systems. The most important design parameter is to achieve good absorptance.

Heat Loss

Once the light changes to heat, the heat will try to leave the absorber as fast as it can. Heat is lost through conduction, convection, and radiation. Designers try to slow heat loss by several methods. With glazing materials, selective surfaces, reflectors, and vacuums there are design trade-offs because they all reduce heat loss, but also reduce the light that reaches the absorber. Insulation levels reduce heat loss but do not affect the amount of light that reaches the absorber.

Reflectors should be understood as more than mirrors. They expand the light gathering area and reduce the heat loss area.

Commercial Considerations

In addition to these design features, other important factors are the cost of the materials and the cost of manufacturing the product. A design may be further influenced by an existing business' product line. Yet after all that, collectors are rather simple.

COMPONENTS

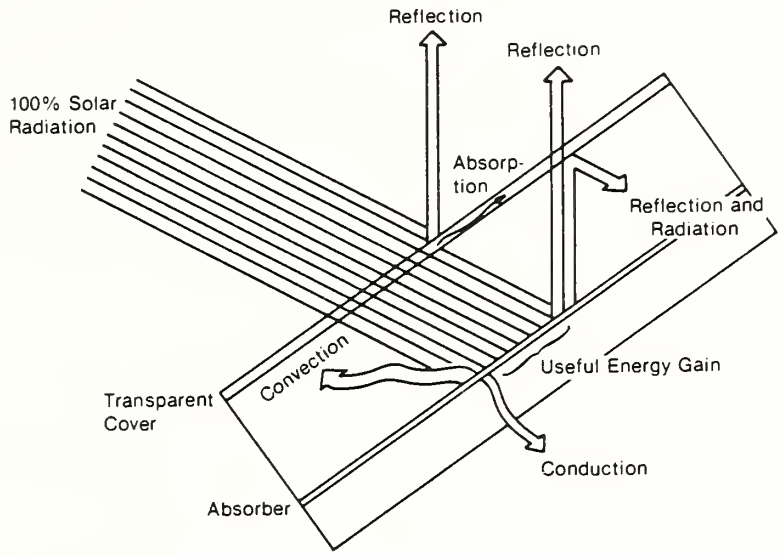
There are four components of flat plate collectors: the glazing, the absorber, the insulation, and the case.

Glazing

The glazing usually consists of one or two layers of glass, plastic, or fiberglass. Glazing minimizes reradiation and convective heat loss and protects the absorber surface. Reradiation is reduced because glass is transparent to short-wave radiation (light) and opaque to long-wave radiation (heat). The absorber converts light to heat. The air space between the absorber and the collector reduces convection.

The two most important criteria in selecting a glazing material are physical properties, and cost. Low-iron tempered glass is the

glazing preference for most manufacturers because of its consumer appeal. Double-glazed collectors are no longer considered preferable because of their weight. Most manufacturers achieve a similar level of performance by using single glazing and a selective surface. Advantages and disadvantages of various materials are compared in the Glazing Comparison Chart at the end of this chapter.

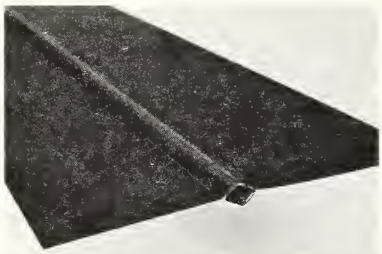


Absorbers

Absorbers for most liquid systems are made of copper, aluminum or steel. An absorber must be a good thermal conductor and must be able to withstand the very high temperatures of stagnation, which are in the range of 400°F. The absorber must be durable and compatible with the other collector materials. Corrosion can occur whenever two dissimilar metals come in direct contact.

The performance of an absorber is determined by its optical quality, that is, its ability to absorb solar radiation. Less expensive absorbers have a flat black surface made of temperature resistant paint. Black paint has both high absorptivity and emissivity (95% absorptivity). Emissivity is the ratio of the radiating power of a material to that of a theoretical "black body" where emissivity equals 1.0.

Selectively surfaced absorbers combine the advantages of very high absorptivity with low emissivity thus being more efficient collector surfaces. These surfaces improve collector performance five to twenty percent, depending on the differential between the working fluid and the ambient temperature. Selective surfaces may be achieved with selective paint or black chrome. Black chrome is electroplated onto polished metallic surfaces in a way that gives a very rough surface structure to the plate. This pitted microstructure inhibits the release of radi-



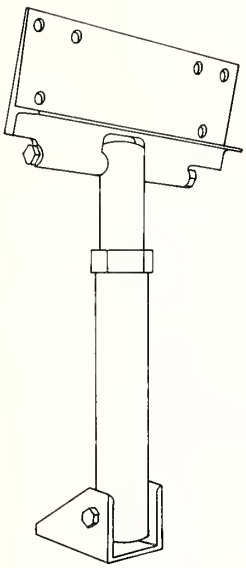
ation. Black chrome is effectively replacing double glazing as a way of increasing collector efficiency in cold weather. Selective paints have absorptivities of approximately .95 and emissivities in the range of .50 to .20. Although they are not as efficient as black chrome, they offer a lower cost and handle more easily.

The absorber provides the heat removal through risers which are attached to the plate by a variety of methods. The perfect bond should be mechanically strong, highly conductive, thin and uniform. If bonding separates because of thermal shock for example, heat transfer is dramatically reduced.

Insulation

Efficient collector operation is completely dependent upon properly installed insulation. Insulation should cover the full perimeter of the panel to reduce edge losses and it must cover the full back of the panel. The most efficient collectors are insulated to R-10 or greater.

Insulation must have sufficient rigidity to not sag in the sloping collector over time. It must not be adversely affected by water in the event it contacts internal condensation. It must be resistant to insects and rodents. Finally, it must be able to withstand temperature swings from below freezing to stagnation.

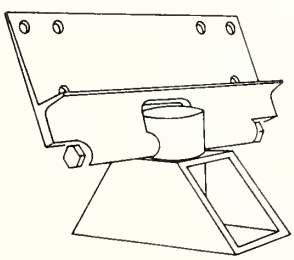


Take care to avoid choosing insulation materials which "outgas" at high temperatures. If "outgasing" occurs a film will be deposited on the underside of the glazing which will reduce transmission of light to the absorber. Most manufacturers use a protective barrier of high temperature insulation between the absorber and other insulations which may not be able to withstand stagnation temperatures.

Case

The case for the collector should be structurally strong and weatherproof for the glazing, absorber, and insulation. The case must also be able to attach to the roof or mounting rack. Most cases are built from aluminum. However, some are built of wood, steel, fiberglass or plastic. Wood and steel cases must be carefully treated for weather resistance.

The design of the case is complicated by the thermal expansion and contraction rates of the various materials involved. Both the glazing and the absorber must be supported yet remain free to expand and contract. Often, glazing is held in the case with a U-shaped rubber gasket. This gasket must be resistant to weathering, ultraviolet degradation and embrittlement.



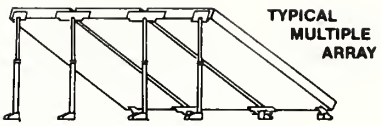
The absorber plate is laid directly on top of the insulation allowing free expansion and contraction within the case.

The cases should have weep holes in the bottom to allow any

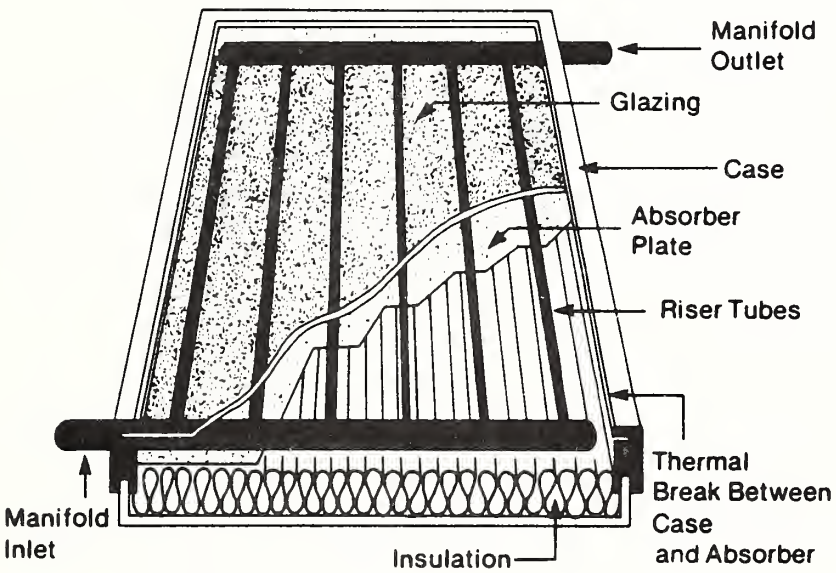
water droplets which may form from internal condensation to drain out.

FLAT PLATE COLLECTORS

Flat plate collectors are by far the most commonly used and most commonly tested collectors for residential solar water heating. Although new designs are constantly being introduced, flat plate collectors are the standard.

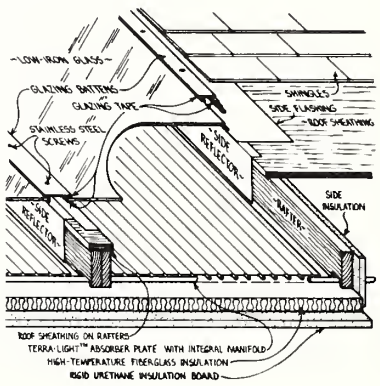


The effective operating temperatures of flat-plate collectors are from 50°F to 180°F. This range makes them close to perfect for residential needs, including space and pool heating in addition to water heating. Their cost can be kept reasonably low. As a rule, you get what you pay for. As the industry has matured, collector sizes have increased and 4′ x 10′ collectors have become common.



SITE-BUILT COLLECTORS

Site-Built Collectors are constructed into the roof and present an evenly glazed skylight appearance. They are assembled at the job location with the same materials used throughout the solar industry in manufactured models.



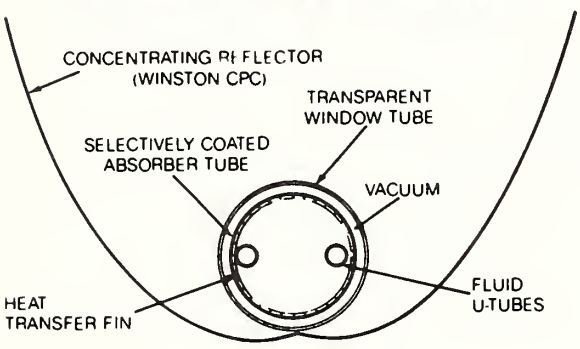
A wide range of glass and absorber sizes allow Site-Built collectors to fit in 24″, 36″ and 48″ on-center framing. The collector can be built into the rafters of an old or new building. Aluminum side reflectors protect the rafters and bounce sunlight onto the

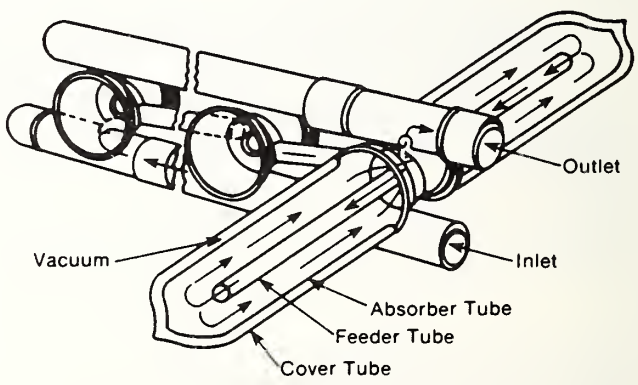
absorber plates. Site-Built collectors are weather tight and versatile. They can be built into existing roofs or new roofs, greenhouses or in freestanding arrays.

CONCENTRATING AND EVACUATED TUBE COLLECTORS

These collectors are designed for high temperature collection. However, they are often installed in residential SDHW systems. Concentrating collectors that do not track are relatively simple. They have no moving parts and can concentrate the sun up to two times. If a higher concentration is needed, tracking concentrators must be used.

CONCENTRATING REFLECTOR AND VACUUM TUBE RECEIVER





The evacuated tube collector focuses radiation via a parabolic reflector onto a vacuum tube. The vacuum effectively eliminates convective heat losses thus making the collectors highly efficient. The collectors are linked together in parallel to a shared manifold. Liquid or gas may be used as the heat transfer medium. Evacuated tube collectors can diffuse radiation effectively. This makes them attractive in climates with a high level of annual cloud cover.

A COMPARISON OF GLAZING MATERIALS

Advantages	Disadvantages
Glass	
Excellent transmissivity	Difficult to site fabricate
Resistant to heat, UV & abrasions	Low impact resistance
Low thermal expansion/contraction	Cost
Easily available	
Transparent	
Acrylic	
Excellent transmissivity	Susceptible to abrasions
Good UV and weather resistance	High expansion/contraction rate
Will not yellow	Becomes brittle with age
Lightweight	Cost
Easy to site fabricate	Low service temperatures
Polycarbonate	
Good service temperatures	Poor weatherability
High impact resistance	Poor UV resistance (yellows)
	Scratches easily
	Not easily available
	High expansion/contraction rate
Fiber Reinforced Polyester	
Low cost	Susceptible to UV, dust, and
High strength	pollution degradation
Good weatherability (in Tedlar	Yellows with age
coated panels only)	High expansion/contraction rate
Easy to fabricate and install	
Laminate: Acrylic/polyesters	
Combines weatherability with	Non-reversible
high service temperature	Susceptible to wind flapping
Good transmissivity	
Polyethylene	
Inexpensive	Poor UV and weather resistance
Easy to install	Low service temperature
Easily available	Fragile
Polyester	
Low-cost	UV degradable unless treated
High service temperatures	Poor optical clarity
Fluorocarbons	
Excellent weatherability	High I.R. transmission
Good strength	Not easily available
Good transmissivity	Susceptible to wind flapping
High service temperatures	Fragile
Long life	
Silicone Coated Cloth	
Good transmissivity	Susceptible to wind flapping
High service temperatures	Susceptible to tearing
Extremely weatherable	

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Design Note 1

The Collector Efficiency Curve — What It Is and How It Is Used

William A. Wright

Introduction

The notion of efficiency is one which is well understood. Economists, business people, engineers and others who measure how much of a product is produced per unit of input generally use efficiency, the ratio of output to input, as a measure of performance. Most physical phenomena, as shown in Figure 1. can be

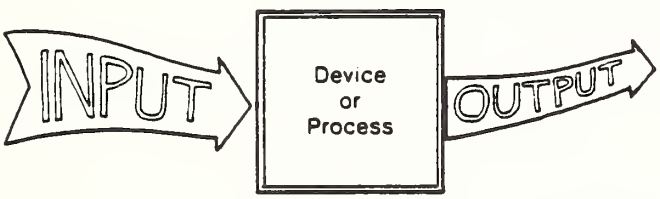

Figure 1.

described simply as input-output situations with a mediating "black box" between them. The inputs and outputs may be variables of any nature as long as the output is the desired product and the input is the source. For example, if the box in Figure 1 is a health insurance plan, then the input is the flow of premiums and the output is the flow of payments. Obviously, the efficiency of such a system is less than 1, because every dollar paid out requires that more than one dollar be paid in. This occurs because of administrative and other necessary costs. From the point of view of plan members, those dollars paid in which do not result in services are a loss, and hence the box in Figure 1 is constructed functionally so that output can never equal input. We are also aware that the efficiency of the plan can be a function of variables such as organization, policy, personnel, general condition of the economy, etc. For each set of external conditions and internal particulars, the efficiency of the plan will vary.

In a similar manner, a solar collector can be understood generally as a device which has solar radiation as an input and some useful form of energy as an output. Although we have made a mental transition from an input of dollars tc an input of energy BTU's or KWH's, the concept is still the same as shown in Figure 1. The box in the figure, when viewed as a collector, represents any device, structure, or system which collects solar energy and provides useable energy as its output. The ratio of useable output energy to solar (input) energy is called the collector efficiency and is shown in equation (1) where η = efficiency.

$$\eta = \frac{\text{Useable output energy}}{\text{Solar energy input}} \qquad (1)$$

The Solar Collector

Many things, either natural or man-made can be solar collectors. A tree is a natural solar collector: it also converts solar energy into potential useable energy by producing wood which we can then burn. A photocell is a man-made collector: it converts solar energy directly into electricty. In general, a solar collector is also a converter; that is, solar light is rarely used directly (although natural lighting is beginning to achieve its pre-fossil-energy importance). Solar light is used. instead, to produce heat, because the simplest conversion of solar energy is the conversion to heat. Owners of cars with black upholstery are familiar with this conversion phenomenon when they park their cars in the sun. The solar radiation which falls on the seat is absorbed by the black surface. but this absorbed energy does not remain in the form of .light. Instead, the solar energy is converted to heat and thus raises the temperature of

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the seat. Most surfaces which absorb solar energy convert most or all of that energy to heat.

The conversion to heat is accomplished so simply that using solar energy as a replacement for nonrenewable heat sources is recognized as an immediately appropriate and viable use of solar energy. Consequently, solar equipment has been developed for heating homes and for making domestic hot water. Figure 2 is a simplified

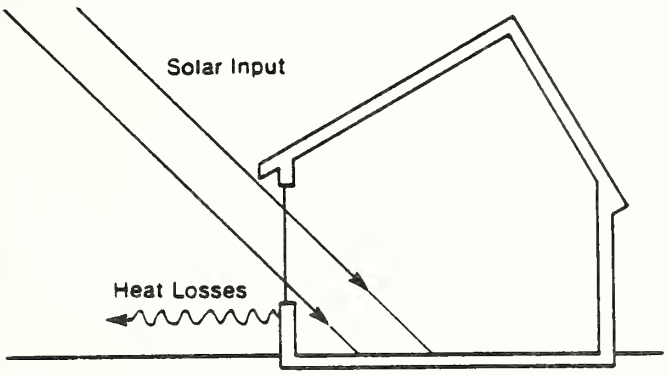


Figure 2. Simplified diagram of a house used as a solar collector.

schematic of a house in which the building itself is used as a collector. By absorbing the sunlight which is transmitted through south-facing glass, the interior surfaces of the house become light-to-heat converters. The heat thus produced can be used to keep the house at a temperature which is comfortable to the occupants.

Because the house is itself the user of the heat produced, it makes good sense to collect the solar energy at the house and to convert it directly to heat internally. The heat doesn't have to be produced in one location and then transported to a different location for use. However, when water is being heated for showers, laundry and industrial processes, it is not always practical to absorb the solar input at the end-use point. Under these conditions, it becomes necessary to convert the solar energy to heat at one location, and then to transport the heat either to storage or to the actual point of use.

When a separate device is used to perform the light-to-heat conversion, that device is generally known as a *solar collector*. The simplest manufactured form of solar collector is a flat, black plate which is placed in the sun. A fluid is passed over the plate to absorb the collected heat which has been produced by the solar energy striking the plate. Thus each input quantity of fluid removes a quantity of heat from the collector by rising in temperature as it contacts the surface. Figure 3 shows such a solar collector.

Collector Efficiency

As in most work systems, input is always greater than output; thus the collector shown in Figure 3 will always have an efficiency of less than 1. That is, the heat extracted by the fluid will always be less than the solar energy collected by the plate.[1] In the same manner that the insurance plan has losses, the flat plate collector has its losses. In Figure 3 the warm surface of the plate loses heat to the atmosphere by convection and by radiation. The convection losses occur because the plate is warmer than the air, and thus heat is transferred from the plate to the air. Radiation losses occur because the plate, like all objects, radiates energy to its surroundings. Energy is exchanged between two surfaces when one surface radiates more energy to the other than is

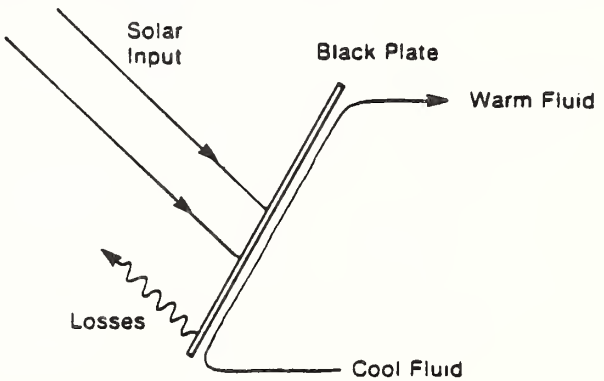


Figure 3. A simple flat plate solar collector.

returned. Because the collector surroundings (the sky and clouds) are cooler than the plate, less radiation from the sky falls on the plate than the plate sends to the sky. This net loss in exchanged radiation is the "radiation loss."

If we assume that solar energy is the only

[1] Extracting heat from the collector via heat pumps can, under certain circumstances, cause heat to be obtained both from the ambient as well as the sun. Such applications are unusual and are not considered here.

energy that enters the plate, then the absorbed energy finds its way to two outlets: useful heat extracted by the fluid, and losses. We may state this condition as an equation:

useable heat = absorbed solar energy − losses (2)

To find the efficiency of the collector, we need only divide the useable heat (output) by the incident solar radiation (input). Since (2) is an equation, we divide both sides of the equation by incident solar radation and obtain η , the efficiency:

$$\eta = \frac{\text{absorbed solar}}{\text{incident solar}} - \frac{\text{losses}}{\text{incident solar}} \quad (3)$$

The Components of Efficiency

The first term on the right hand side of equation (3) is the ratio of absorbed solar to incident solar. Notice that as this ratio increases toward 1, the efficiency of the collector also increases. Notice also that if the second term were zero (no losses) the efficiency would simply be equal to this ratio. Thus the ratio of absorbed to incident solar is a very important term: the maximum efficiency which could be obtained by a collector. For our simple collector, the ratio is equal to the solar absorptance, usually designated by α, which is a characteristic of the surface layer, and not of the underlying material. A black surface generally has an absorptance between .9 and .98. Thus we may replace the first term on the right side of equation (3) by α and equation (3) becomes:

$$\eta = \alpha - \frac{\text{losses}}{\text{incident solar}} \quad (4)$$

The second term on the right side of equation (4) is the ratio of energy lost to incident energy. No simple definition exists for this ratio; we must evaluate the numerator and denominator separately. The numerator is generally estimated by the crude assumption that the losses are proportional to the difference between the plate surface temperature (T_p) and the ambient air temperature (T_a) or

$$\text{losses} = \text{constant} \times (T_p - T_a) \quad (5)$$

The constant in equation (5) combines the losses due to convection and radiation into one term. Heat transfer experts generally do not favor this approximation, as it is only true over a narrow range of conditions, especially in the case of Figure 3, a flat-plate collector, which does not have a transparent cover plate. We will disregard this point for the moment and simply name the constant U_L, the total heat transfer coefficient of the plate per unit area. Thus, equation (5) becomes:

$$\text{losses} = U_L (T_p - T_a) \quad (6)$$

The symbol commonly used for the incident solar radiation is H, where H is units of energy per unit area per unit time (BTU/FT²/HR or KW/M²). The ratio of losses to incident solar is obtained by simply dividing both sides of the equation (6) by H:

$$\frac{\text{losses}}{\text{incident solar}} = \frac{U_L (T_p - T_a)}{H} \quad (7)$$

We may now substitute equation (7) into equation (4). We obtain:

$$\eta = \alpha - \frac{U_L (T_p - T_a)}{H} \quad (8)$$

Notice that whenever $U_L (T_p - T_a)$ is small compared to H, that η is very nearly equal to α , the maximum efficiency. Clearly, no matter what the value of H is, whenever T_p is nearly equal to T_a, the collector efficiency is highest. This tells us that operating the collector so that the collector plate is near ambient temperature is one method for obtaining high efficiencies from the collector.

Suppose that the efficiency, η , is zero. This means that no useful heat is being extracted from the collector. This condition could be obtained by simply placing the collector in the sun and not passing any fluid over the plate. Unless the incoming energy can be stored, equation (8) tells us that

$$\frac{U_L (T_p - T_a)}{H} = \alpha \quad (9)$$

must be true whenever $\eta = 0$; that is to say, all of the absorbed solar energy must be lost as

heat to the air whenever $\eta = 0$. Since α, U_L, H, and T_a are fixed by materials or by the environment, T_p is the only quantity which can vary. In order for the left side of equation (9) to be a positive number (it must be, since α is between 0 and 1), the plate temperature must be greater than the air temperature. In fact, if we place the collector of Figure 3 in the sun, then the plate temperature will rise until equation (9) is satisfied and then T_p can no longer increase. This temperature is called the stagnation temperature. In the summer, when ambient temperatures may be 80°F, the stagnation temperature of the simple black plate in Figure 3 may be 160°F. Such temperatures may be destructive to the plate or its surface, and so the ability to calculate the stagnation temperature is quite useful in estimating worst case conditions. Equation (8), then, can tell us a great deal about how to operate a collector, and what temperatures and efficiencies the collector may obtain.

Adding a Cover

The simple black plate without a cover has found good use in low temperature applications during the summer. Swimming pool heaters are a good example of such an application. The difference in plate and ambient temperature may only be a few degrees when swimming pool water is heated, but for other applications, such as domestic hot water, the difference in plate temperature and air temperature may be in excess of 100°F. For example, a sunny winter day may have an air temperature of 20°F and we may desire to heat water to 140°F. Under such conditions, the value of U_L becomes very important. On a cold, windy, clear day, U_L could be easily enough so that a T_p of 140°F would result in a negative efficiency. In other words, such a collector would reach stagnation at temperatures below those which provide useful amounts of heat.

Since α and U_L are the only two collector related numbers in equation (8), a change in the collector could only be effected by changing either α or U_L. Since α is typically .9 and never above 1.0, increasing α offers little opportunity for improvement. The ideal approach would be to decrease U_L without reducing α. A perfectly transparent cover fills this need. By allowing all the incident energy to pass through, α is maintained. But by insulating the plate from the ambient air with a dead air layer between the plate and the cover, U_L is reduced.

In the real world, no such thing as a perfectly transparent cover exists. Glass and plastics transmit only a fraction of the incident radiation. That transmitted fraction is called the transmission, τ, defined as:

$$\tau = \frac{\text{transmitted energy}}{\text{incident energy}} \qquad (10)$$

Real transparent covers such as glass have a pleasant secondary beneficial effect, involving frequencies of incoming and radiated energy. The radiation from the plate is invisible because it occurs at wavelengths to which our eye is insensitive. These wavelengths, longer than visible light, are called the far infra-red or simply IR. Many glasses and plastics have the characteristic of high visible light transmission (.8 to .95), while the IR transmission is low (.05 to .2). Thus radiation which is transmitted through the cover is absorbed by the plate (see Figure 4), converted to heat and then re-radiated by the plate at IR wavelengths. These IR wavelengths are not transmitted by the cover to the sky, however; rather, they are absorbed in the glass. The net result of this phenomenon is that radiation losses are reduced by "trapping" the radiation.

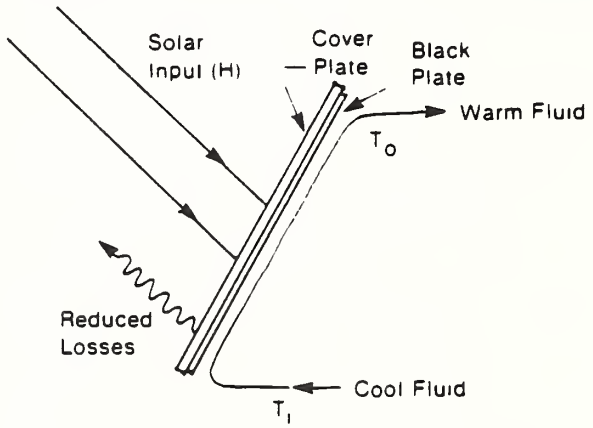


Figure 4. A single cover flat plate solar collector.

The combined reductions of radiation and convection losses coupled with a small decrease in energy transmitted to the plate causes the collector to be more efficient when there is a higher

temperature difference between the plate and the ambient. In order to incorporate this new cover into our equation for efficiency, we return to equation (3). The first term on the right hand side is absorbed solar divided by incident solar. Since the energy transmitted through the cover is obtained from equation (10) as τ times the incident, that energy which falls on the plate will be τH. Thus if we return to our earlier definition of α, we may conclude that the fraction of τH which will be absorbed is α, or:

$$\text{absorbed energy} = \tau \alpha H \qquad (11)$$

and if the first term on the right of equation (3) is divided by H, it simply becomes

$$\frac{\text{absorbed energy}}{\text{incident energy}} = \tau \alpha \qquad (12)$$

Equation (12) is not strictly true, because the visible solar which is not absorbed by the plate is reflected and bounces back to the cover. A portion of this reflected energy is transmitted out of the collector, but a small amount is reflected back onto the plate. This bouncing back and forth gives rise to slightly more energy being absorbed than $\tau \alpha H$, but the difference is small. The combined effects of geometry, τ and α, yield an "effective transmission absorptance product" which is usually indicated by $\overline{\tau \alpha}$. The second term on the right of equation (3) is the ratio of loss to incident energy. Since the incident energy is still H, we need only consider possible changes in loss. Equation (6) shows us that loss is a function of U_L, T_p and T_a. Since U_L is the only term of these three affected by adding a cover, we see that no changes are needed in the *form* of equation (6). Although the numeric value of U_L may change, the concept that loss is proportional to temperature difference is still valid. As a matter of fact, heat transfer experts will feel a little better due to the fact that the addition of the cover has widened the range of conditions under which the engineering approximation for loss is fairly accurate.

The substitution of the corrections for the cover into equation (3) then yields:

$$\eta = \overline{\tau \alpha} - \frac{U_L (T_p - T_a)}{H} \qquad (13)$$

which isn't much of a change from equation (8). The maximum efficiency for the collector is now $\overline{\tau \alpha}$, and U_L will have a lower value, but the form of the equation is the same. In a similar manner we could add a second cover to the collector and both $\overline{\tau \alpha}$ and U_L would change in their numeric value, but equation (13) would still be true for two (or more) covers.

How Flow Is Involved

We have only one additional real world modification to make. When we discussed loss, earlier, no consideration was given to variations in plate temperature. If the fluid which extracts heat from the collector enters at a lower temperature, T_i, and leaves at a higher temperature, T_o then how does that relate to T_p? If the plate is in contact with the fluid, then surely the plate temperature is affected by the fluid temperature. It is, as a matter of fact. In order for the fluid to extract heat at an appreciable rate, the plate and fluid temperatures will be fairly close. But this means that the plate temperature must be higher at the fluid outlet than at the inlet. Indeed, the plate temperature varies continuously over its surface. Equation (13), you will note, simply indicates T_p, which is another way of saying that equation (13) is really only true for small, local areas of the collector. Also note that as T_p changes, so does η. Furthermore, in the real world, the measurement of η requires the measurement of T_p. But if T_p varies, then where should one measure it?

From a measurement standpoint, it is more convenient to measure T_i or T_o in the fluid than to measure varying internal temperatures such as T_p. If we substitute T_i (in place of T_p) into equation (13), then we would get an answer for η which would be not quite right. In order for η to represent the entire collector, and for T_i to replace T_p, we must correct the right side of equation (13). The mathematical derivation for such a correction factor depends upon the fluid, the fluid flow rate, the collector-fluid interface and the interface geometry. All of these factors are required in order to relate T_i and T_p for a particular collector. Such factors have been derived, and are beyond the scope of this Design Note. For convenience, we define a factor, F_R, to include these effects

such that:

$$\eta = F_R \left\{ \overline{\tau\alpha} - U_L \left(\frac{T_i - T_a}{H} \right) \right\} \qquad (14)$$

Thus, we multiply the entire right side of equation (13), with T_p replaced by T_i, by the factor F_R which allows η to be defined in terms of T_i instead of T_p. Equation (13) behaves much the same way as equation (8). That is, the maximum value of η still occurs when $T_i = T_a$ except that now the maximum value of η is $F_R \overline{\tau\alpha}$. Notice that when $\eta = 0$,

$$\overline{\tau\alpha} = U_L \left(\frac{(T_i - T_a)}{H} \right) \qquad (15)$$

and F_R plays no part in determining the stagnation temperature. (Remember F_R has to do with the fluid which is extracting heat, and at stagnation, no useable heat is extracted.) We can solve for the stagnation temperature, $T_i = T_s$ as follows:

$$T_s = H \frac{\overline{\tau\alpha}}{U_L} + T_a \qquad (16)$$

Efficiency Graphics

In graphic terms, equation (14) represents a straight line. Figure 5 shows a graph of the collector efficiency equation. The vertical axis represents efficiency, η, and the horizontal axis

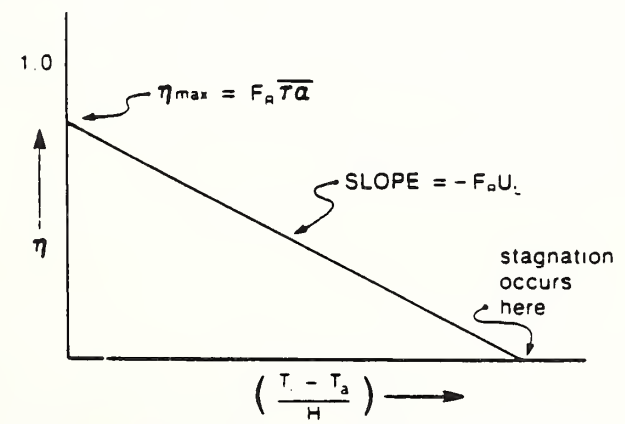


Figure 5. The collector effeciency curve.

represents $(T_i - T_a)/H$. Note that the maximum value of η occurs when $T_i = T_a$ and is $F_R \overline{\tau\alpha}$. The line representing efficiency slopes downward as $(T_i - T_a)/H$ increases, at a rate of F_RU_L. The intersection of the efficiency line with the horizontal axis occurs when $\eta = 0$ and hence indicates the conditions under which the collector stagnates.

Note that as $(T_i - T_a)/H$ decreases, the resulting efficiency increases. One must conclude that it is preferable to operate a collector for the lowest values of $(T_i - T_a)/H$ that can be arranged. Of the three variables T_i, T_a and H, only T_i is under the designer's control. Thus, if the designer can meet the user requirements with a lower temperature fluid, then a higher efficiency use of the collector will occur. In other words, by using the lowest practical operating temperature, the most energy will be obtained from the collector. This characteristic of collectors can have major impact on both the configuration and type of other components in the system.

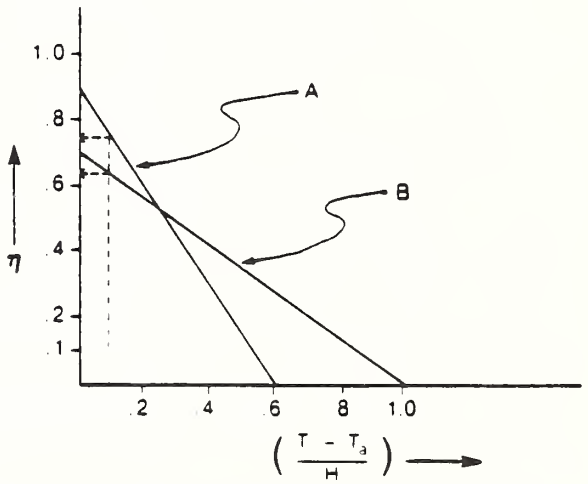


Figure 6. Two typical collector curves.

Although long term predictions are not made solely by using collector curves, certain kinds of design decisions can be made using the knowledge we have gained. Consider Figure 6 which shows 2 collector curves. Curve A, which might represent an inexpensive, single film glazed collector has higher maximum efficiency than curve B, which represents a double glazed, nonselective surface collector. On the other hand, curve A shows a larger slope than curve B, and hence has a higher value of F_RU_L. For values of $(T_i - T_a)/H$ less than 0.25, the type A collector will always have a higher efficiency than the type

B. For values of $(T_i - T_a)/H$ greater than 0.25, type B will always outperform A. As a matter of fact, type A will produce no output for $(T_i - T_a)/H$ greater than 0.6, whereas type B will continue to produce heat until $(T_i - T_a)/H$ equals 1.0.

Thus, if the most likely operating conditions are known, so that $(T_i - T_a)/H$ can be reasonably well predicted, then a collector type could be selected which performs best. Suppose that we desire to heat a swimming pool. If the typical water temperature is 75°F and T_a averages 50°F, then $(T_i - T_a)/H$ will vary from 0.25 to 0.10, for H between 100 and 250 BTU/Ft²/hr. In particular, at 250 BTU/Ft²/hr. $(T_i - T_a)/H = 0.1$ and the efficiency of type A is 0.75, whereas type B is only 0.63. In other words, type A will produce 30 BTU/Ft²/hr. more heat than type B under these conditions, and thus type A is a better choice from an efficiency point of view.

In a similar manner, if the application were changed to domestic hot water heating, and $(T_i - T_a)$ reached values on the order of 75°F to 100°F, then most of the time, the collector would operate at values of $(T_i - T_a)/H$ above 0.25, and clearly type B would be the best choice. (It is important to note that T_i is determined by the entire system, and that generalities regarding collector type and application are difficult to make. For example, some designers are now using large storage tanks for active space heating systems, and thus forcing lower temperature operation. Under such conditions, our logic might well reverse the above choice, and thus negate a generality regarding collector type and space heating.)

Curves such as Figure 5 are measured by independent laboratories for most manufactured collectors. The curves and their operating conditions are the manufacturer's thermal specifications. Although other data may be required, the curves are a standardized means of comparing collectors. It is important to notice that T and H are instantaneous values. Although we have seen that it is possible to use this curve to determine how a collector will perform under specific conditions, it is not possible to use this curve to easily project how well a particular collector will perform over a longer period. This frustrating fact is due to the fact that T_i is influenced by storage size and type, the nature and timing of load, and the system controls; T_a and H are difficult to characterize in a manner which allows easy coupling with system parameters. Thus, the development of long term collector performance techniques has been a lengthy effort which has resulted in computer programs (TRNSYS, FCHART, SOLCOST) which are specialized and beyond the scope of this discussion. It is important to note that a designer must be able to extract $F_R\overline{\tau\alpha}$ and F_RU_L from test curves because most long term prediction methods require these collector characteristics as one input.

Consider Figure 5 again. To find $F_R\overline{\tau\alpha}$, we must remember from equation (14) that when $(T_i - T_a)/H$ is zero that η becomes η_{max} and that η_{max} is equal to $F_R\overline{\tau\alpha}$. Thus for type A, $F_R\overline{\tau\alpha}$ is equal to 0.9. To find F_RU_L we need only find the slope of the curve. For type A, the efficiency falls from 0.9 to 0.0 as $(T_i - T_a)/H$ falls 0.0 to 0.6 and thus the slope is 0.9 divided by 0.6, or, 1.5 BTU/Ft²/°F/hr. In a similar manner, for type B, $F_R\overline{\tau\alpha} = 0.7$ and $F_RU_L = 0.7$.

Conclusion

The collector efficiency curve is a rich source of information about a particular collector. From the curve, we can determine how the collector will perform under specific conditions. By understanding the basic principles which govern the operation, designers can maximize the output from the collector. Designers who can make use of the implicit information in this curve will generate systems which obtain the best return from their client's investment. In other words, knowing and using the collector efficiency curve is one of the first steps toward good system design.

Glossary

Term	Definition
F_R	The ratio of actual useable heat collection rate to the useful heat collection rate attainable with the entire collector surface at the temperature of the fluid entering the collector. (dimensionless)
H	Incident solar flux (BTU/ft²/hr or W/m²)
η	Efficiency: the fraction of incident solar flux which is extracted as useable heat. (dimensionless)
T_a	Ambient temperature (°F or °C)
T_i	Fluid inlet temperature (°F or °C)
T_p	Local collector plate temperature (°F or °C)
T_s	Stagnation Temperature: the temperature which a collector reaches when no useful heat is extracted. (°F or °C)
U_L	Heat loss coefficient of the collector (BTU/ft²/hr/°F or W/m²/°C)
τ	Transmission: the fraction of incident solar flux which is transmitted through a cover plate (dimensionless)
α	Absorption: the fraction of incident solar flux which is absorbed by a surface (dimensionless)
$\overline{\tau\alpha}$	Effective transmission — absorption product: the fraction of solar flux (incident on a glazed surface) which is absorbed (dimensionless)

This Design Note was prepared by the Systems Design Department of the Northeast Solar Energy Center to promote the application of solar energy in the Northeast. For futher information, contact the Center at 70 Memorial Drive, Cambridge, Massachusetts, 02142.

Siting and Sizing

The collector array must be placed where it will receive the maximum amount of sunlight available in your location. A roof mount is most common because it reduces chances of shading and places the collectors out of the way. If a good roof area is not available, collectors may be ground or wall-mounted. Keep outdoor pipe runs to a minimum to avoid heat loss.

COLLECTOR ORIENTATION

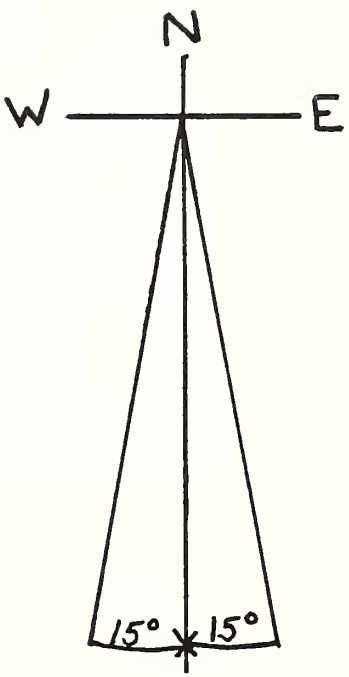
Collectors should be oriented to TRUE south, not magnetic south. Variations of up to 15° east or west of south, will have little effect on performance as long as the system is running properly. It is not worth the added expense to build a special mounting frame to point collectors true south if the roof is pointed within the ±15° limits.

Deviations

Beyond 15°, additional calculations must be performed to determine if the expense is justified. Deviations up to 30° east or west of south will usually decrease performance 10 to 15%. After 30°, performance drops dramatically.

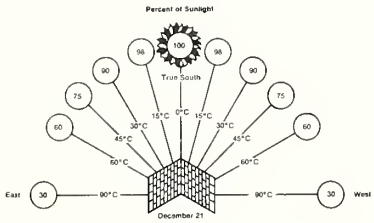
True South

Being aware of true south is critical because the earth's magnetic field is not parallel with the earth's north-south axis; thus, there are some parts of the United States where the needle of a magnetic compass can point as much as 20° east or west of true north. There are several ways to determine true south in your area. You can consult a local surveyor, a plot map in your local tax office, or a recent isogonic chart of the United States published by the U.S. Coast and Geodetic Survey, U.S. Department of Commerce. Adjust your magnetic compass reading according to the meridian nearest to you. Do not use old isogonic



charts, as there are annual variations in the readings. When using a magnetic compass, do not stand near large metallic objects or power lines because they will affect the compass readings. Three separate compass readings should be taken to assure accuracy.

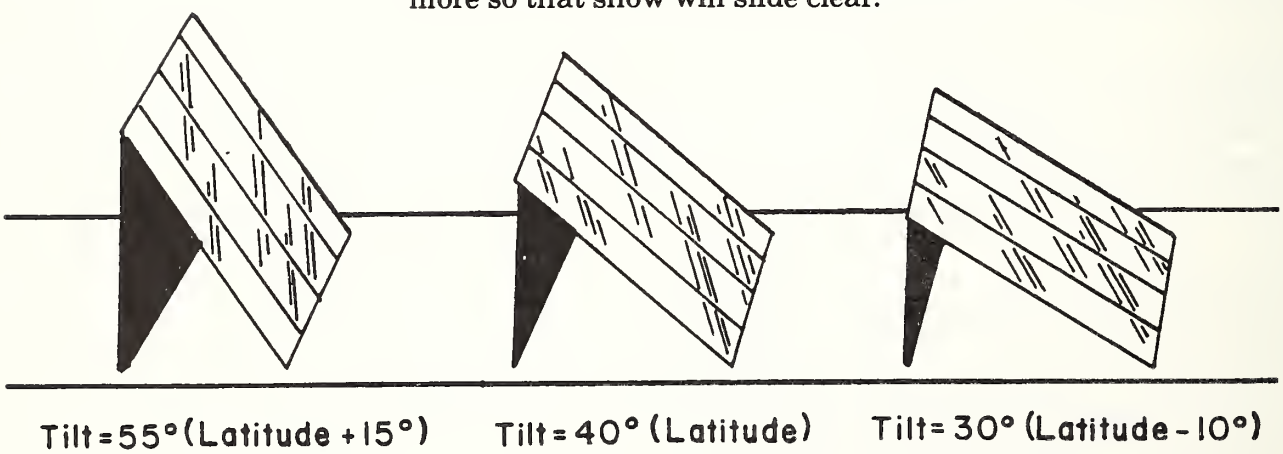
The shadow of a stake cast by the sun at solar noon will be on the true north-south line. Solar noon is exactly halfway between sunrise and sunset on any given day. Most local TV weather shows and newspapers give the exact times of sunrise and sunset.



Although performance will not be substantially affected, you should take local weather conditions into consideration when deciding on collector orientation. Although angling the collectors toward the east will start the system earlier in the morning, orientation slightly to the west can increase system performance because ambient air temperatures are usually higher in the afternoon. As a result, collectors will lose less heat and operate more efficiently. If early morning fogs are common in your area, angle the collectors slightly toward the west.

COLLECTOR TILT

Collector tilt — the angle the surface of the collector makes with the horizon — is also an important factor in system performance. Collectors should be perpendicular to the sun's hottest rays. For a solar DHW system a tilt equal to the local north latitude usually is considered the optimum angle. Variations 10° either way will not seriously affect the total annual performance of the system, but a greater tilt will favor winter system operation when the sun is low in the sky. In heavy snow areas, glass-glazed collectors should be mounted at angles of 40° or more so that snow will slide clear.

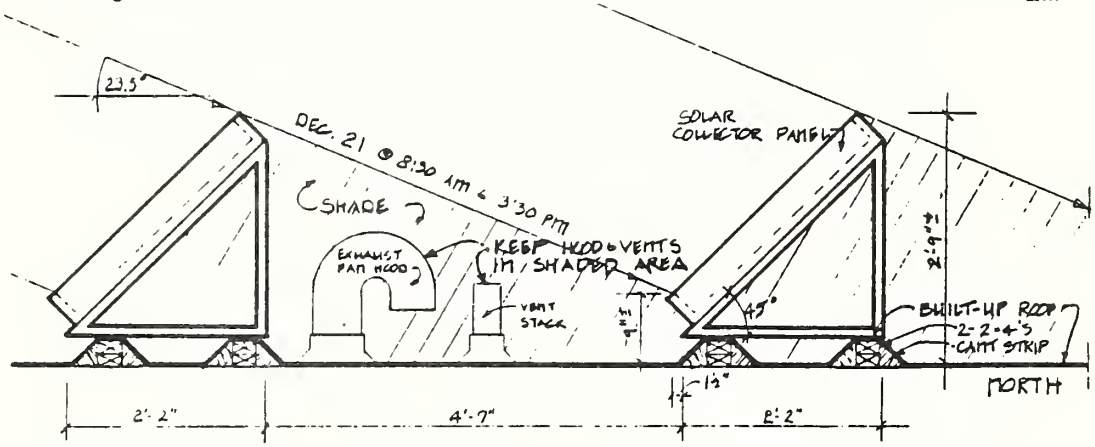


COLLECTOR SHADING

No more than 5% of the collector area should be shaded between 9:00 A.M. and 3:00 P.M. Standard Time which is when the greatest solar potential occurs. One of the major sources of

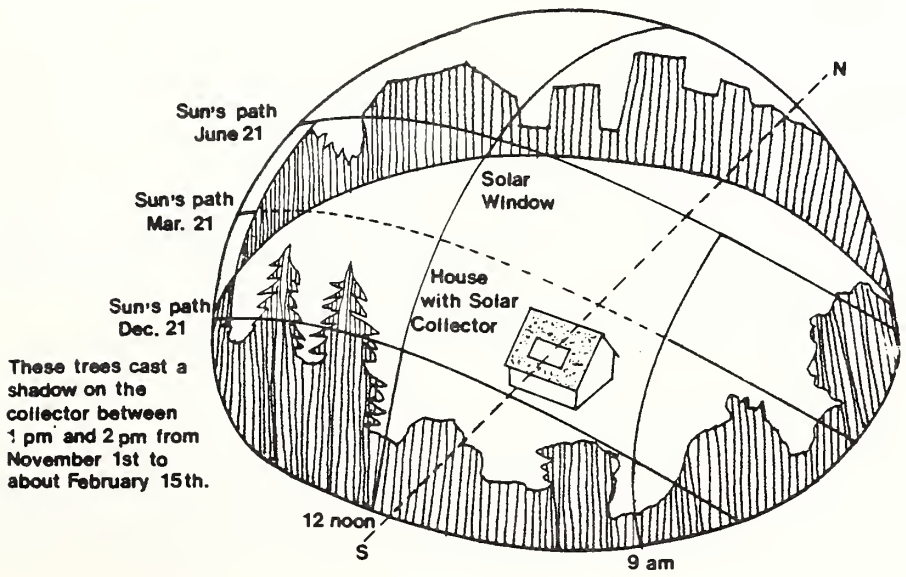
shading is trees, so the home owner should be aware of future growth. Chimneys, dormers, other buildings, new construction, and even fences may shade the collector array, especially in the winter when sun angles are low and shadows are long. By knowing the altitude (angle of sun above horizon) and the azimuth (angle between true south and point on horizon below sun) throughout the year, you can accurately determine shading problems. This information can be plotted on the sun Angle Chart printed in this chapter.

COLLECTOR SPACING: Collector spacing should allow the front collector's shadow to clear the rear collector's glazing. This design is based on December 31 at 8:30 am and 3:30 am



The Solar Window

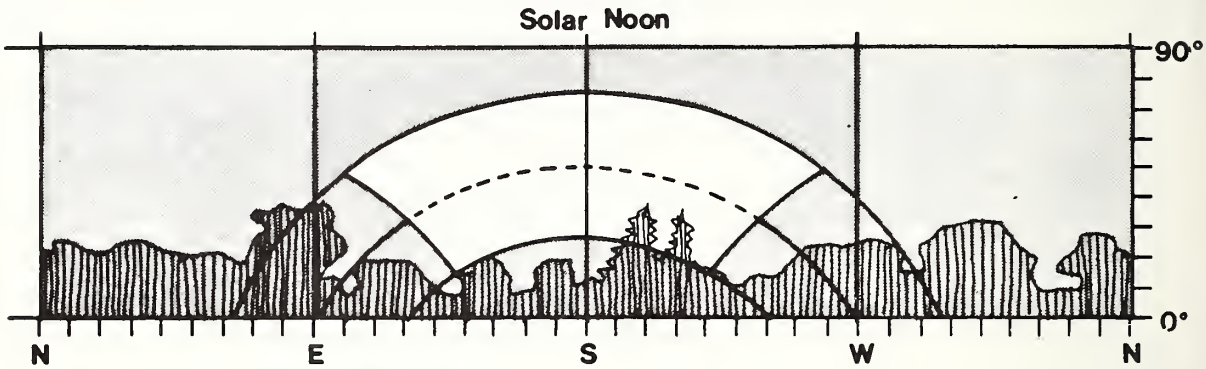
Imagine the sky as a transparent dome with its center at the


Sun's path June 21
Sun's path Mar. 21
Sun's path Dec. 21
Solar Window
House with Solar Collector
These trees cast a shadow on the collector between 1 pm and 2 pm from November 1st to about February 15th.
N
12 noon
S
9 am

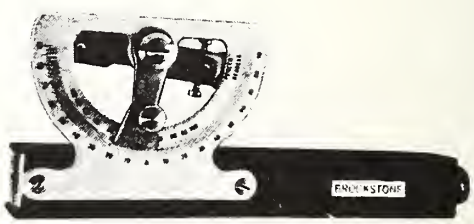
solar collector array. The path of the sun during the year and the outline of surrounding houses and trees can be projected on the dome. The sun's path between 9:00 A.M. and 3:00 P.M. throughout the year makes a "solar window" on the dome. Almost all of the useful sunlight that reaches the collector array must come through this window, except for the amount resulting from diffuse radiation. If any surrounding houses, trees, hills, etc. block part of this window, the intrusion will cast a shadow on the collector. The elevation of the solar window will decrease with increasing latitude.

Siting Tools

The sky dome with its "solar window" can be mapped using a "Mercator Projection" in which the latitude and longitude lines are straight. Such a map is very useful for comparing the site surroundings with the "solar window," because both can be easily plotted on the map. Any elements surrounding the site that intrude into the "solar window" will cast shadows on the collector. Even tree branches without leaves can block a considerable amount of winter sunlight.



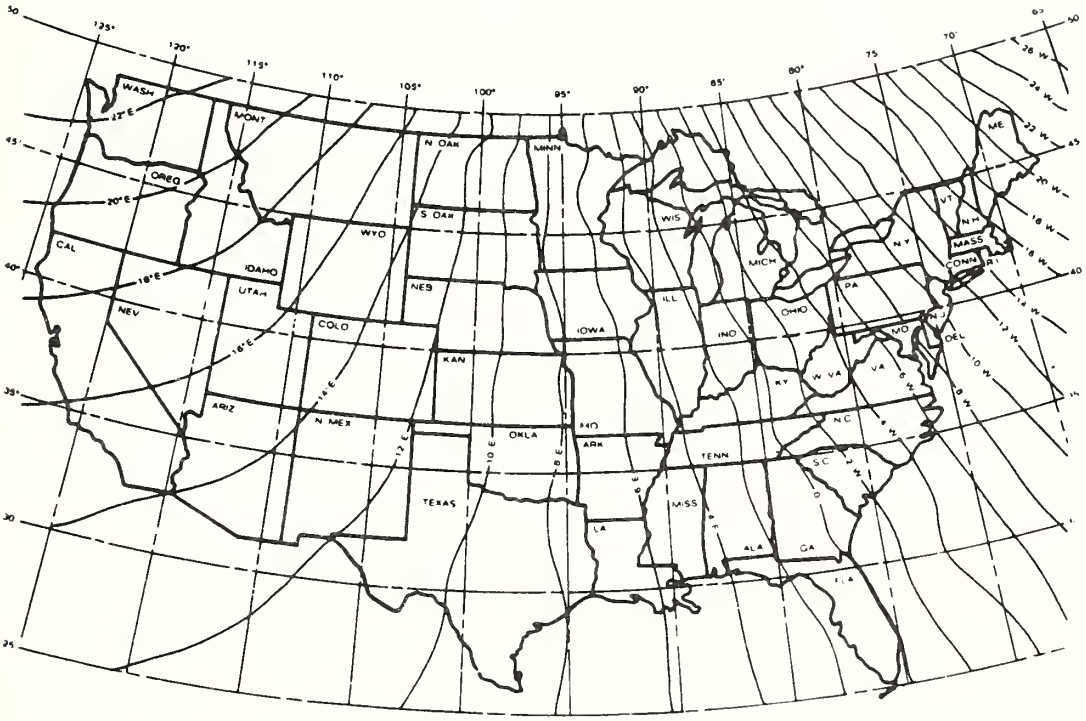
SOLAR PATHFINDER™



Abney Level

The "Abney Hand Level" and the "Sun Chart" also offer ways to evaluate sites. The Abney Level is set at the proper winter sun angle and the installer sites along that line to spot obstructions. By marking the appropriate sun chart for your latitude, you can see what the shading effects will be for each time of year and

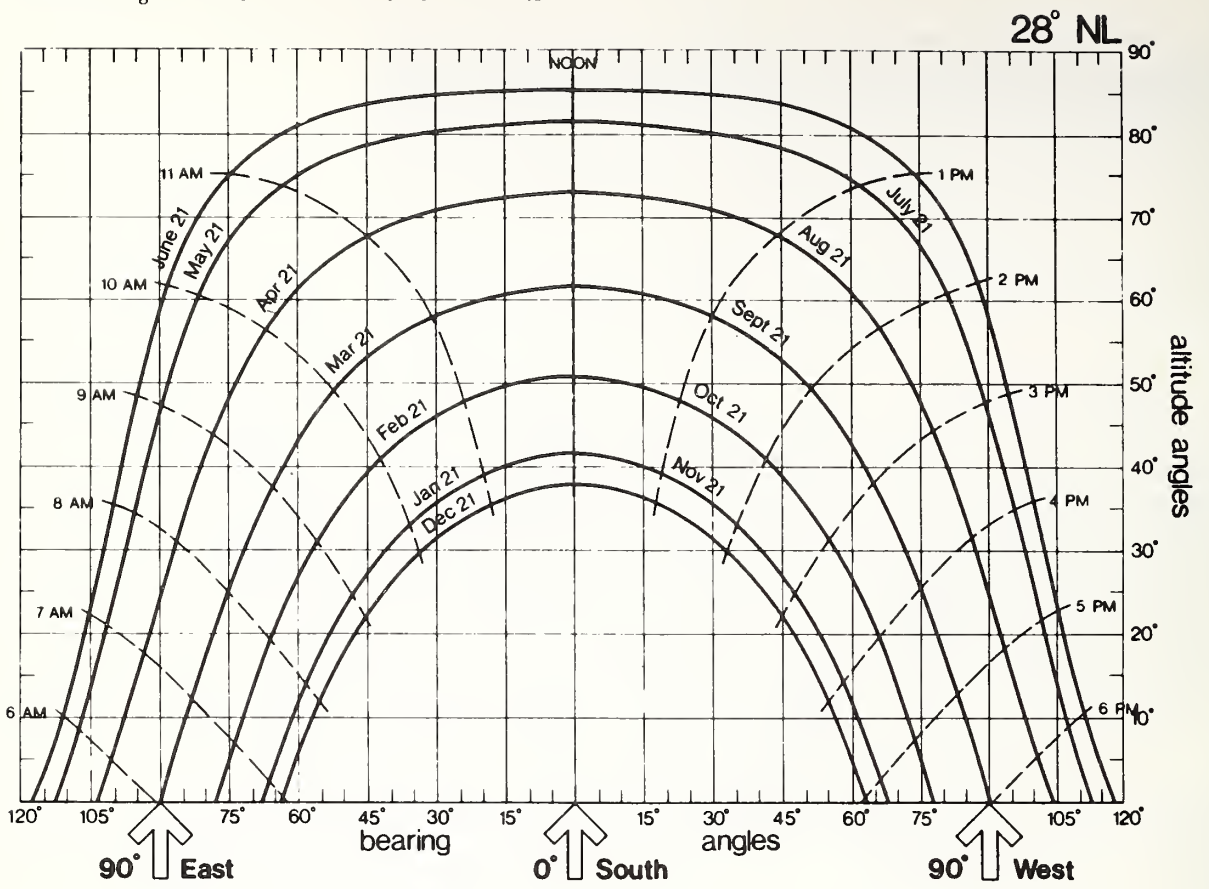
time of day. For more exact readings, tools like hand-held shading masks and the "Solar Pathfinder" are available. The "Solar Pathfinder" can easily give you month by month shading factors.

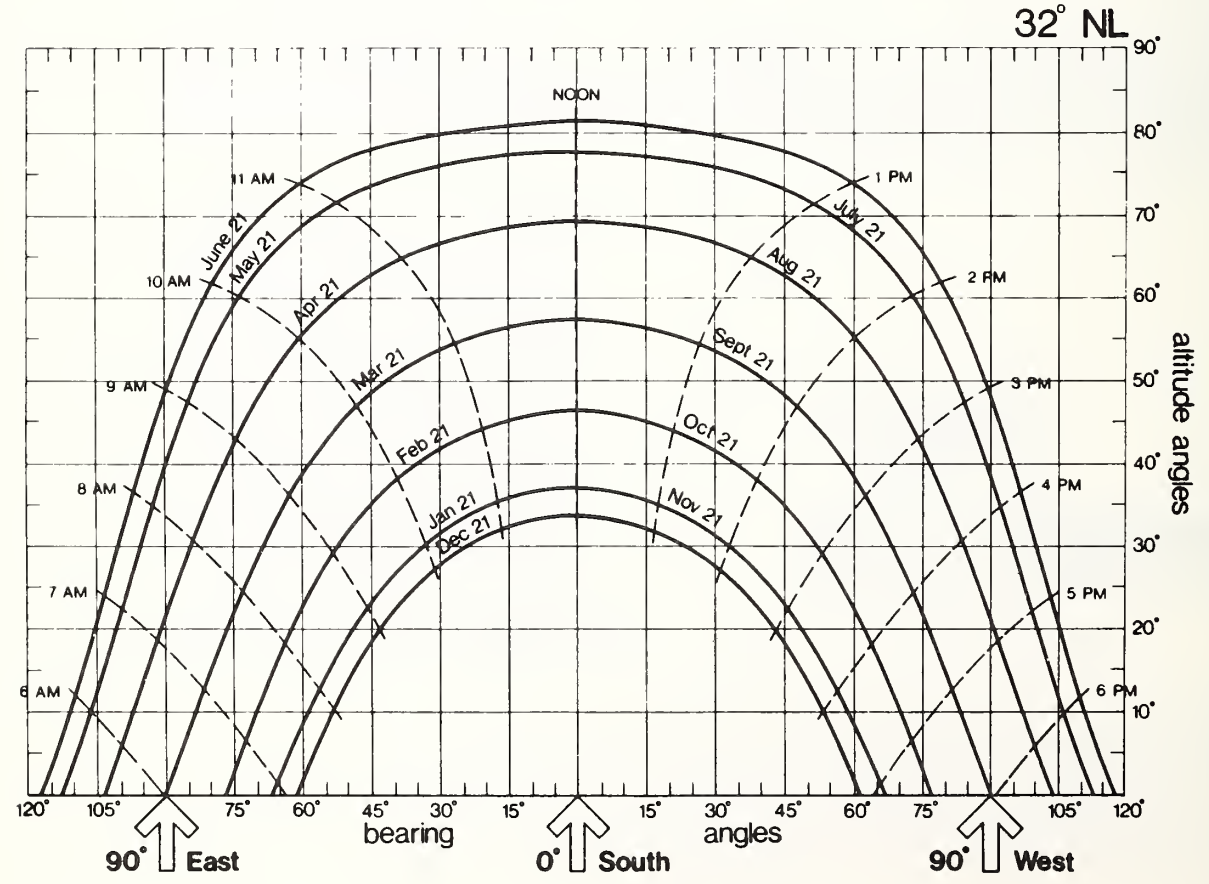


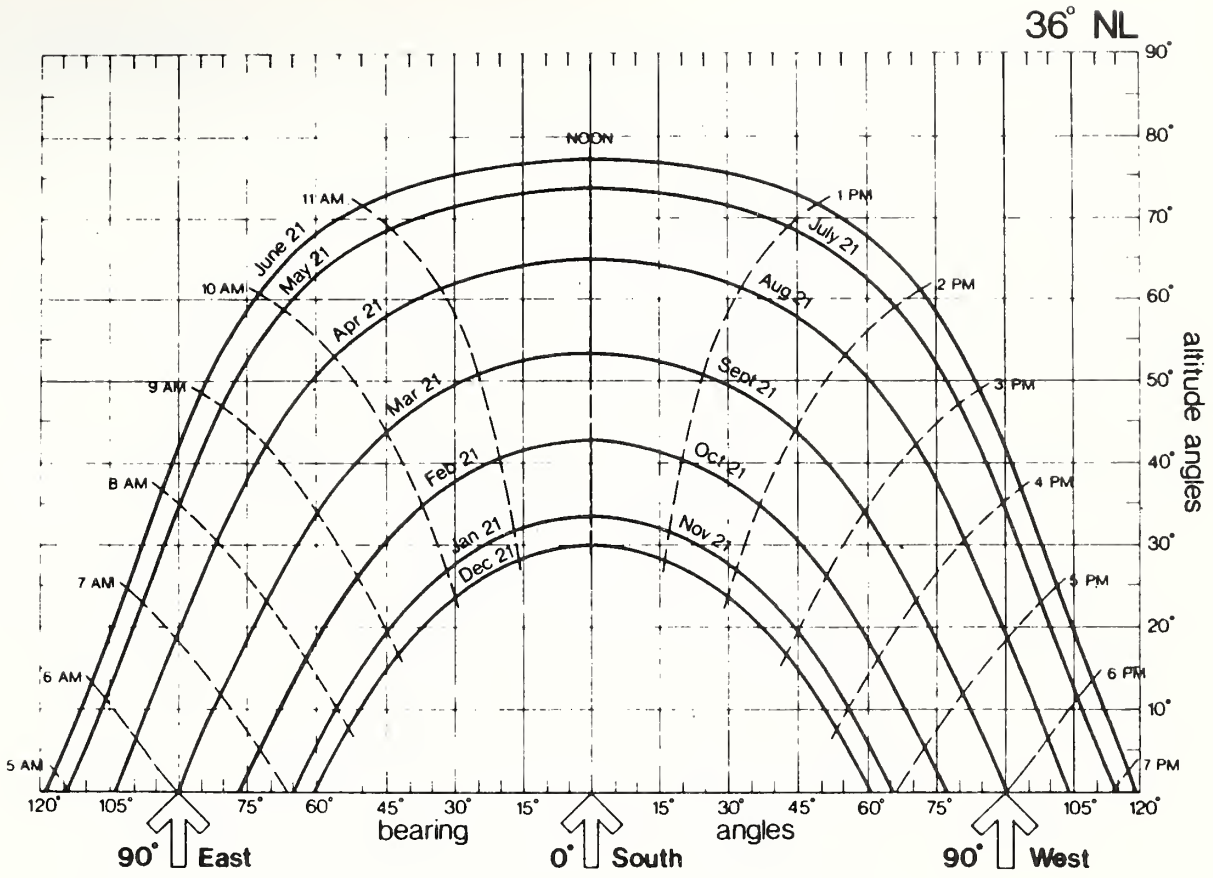
Isogonic Chart of the United States

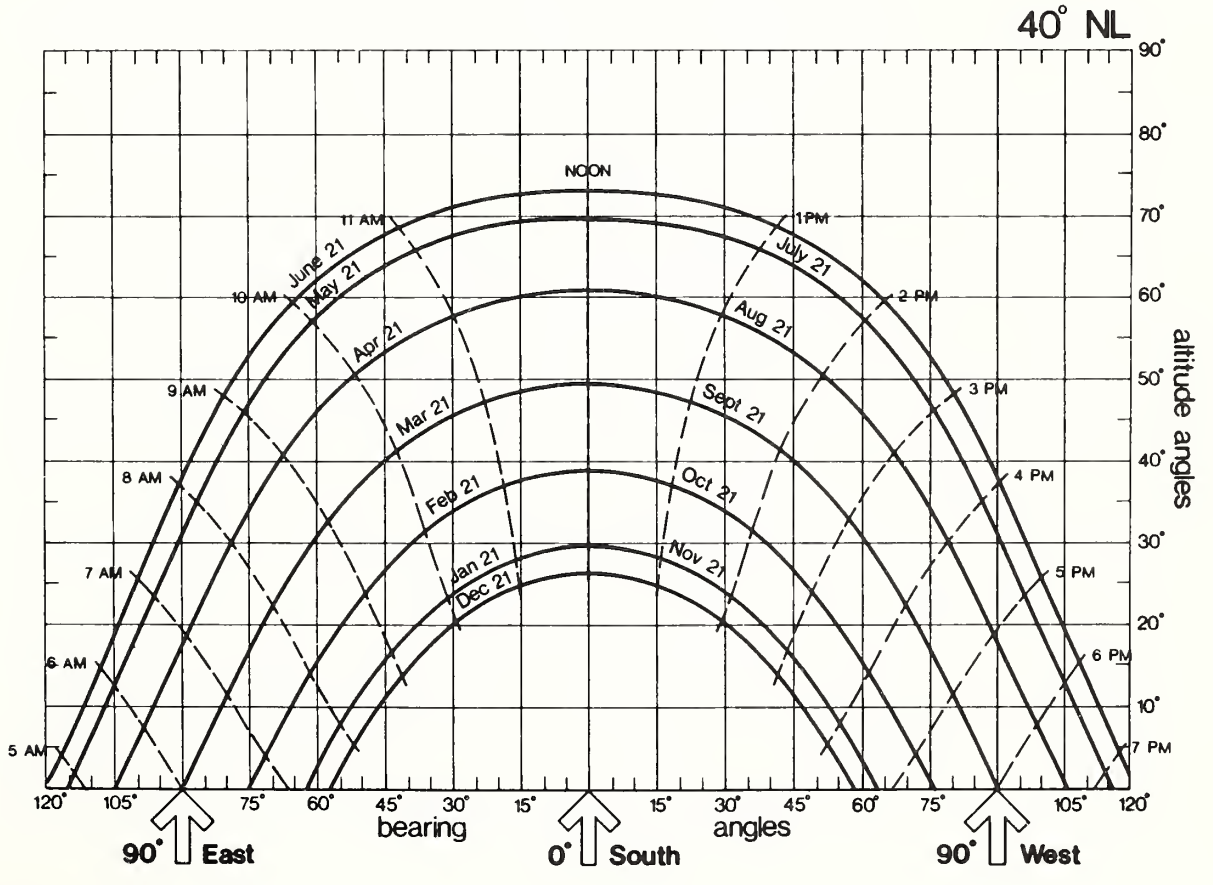
Sun Charts

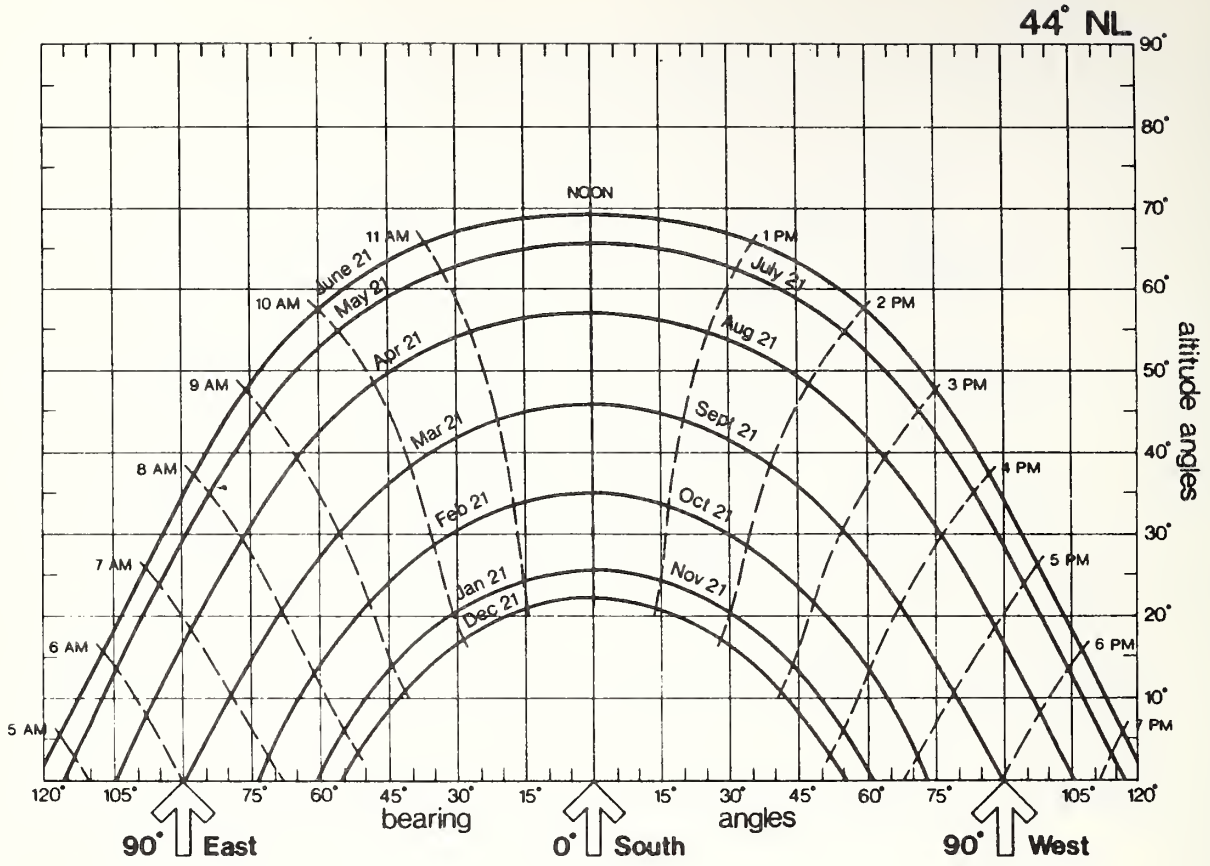
The following sun charts are for all latitudes from 28° to 56°NL at 4° intervals.

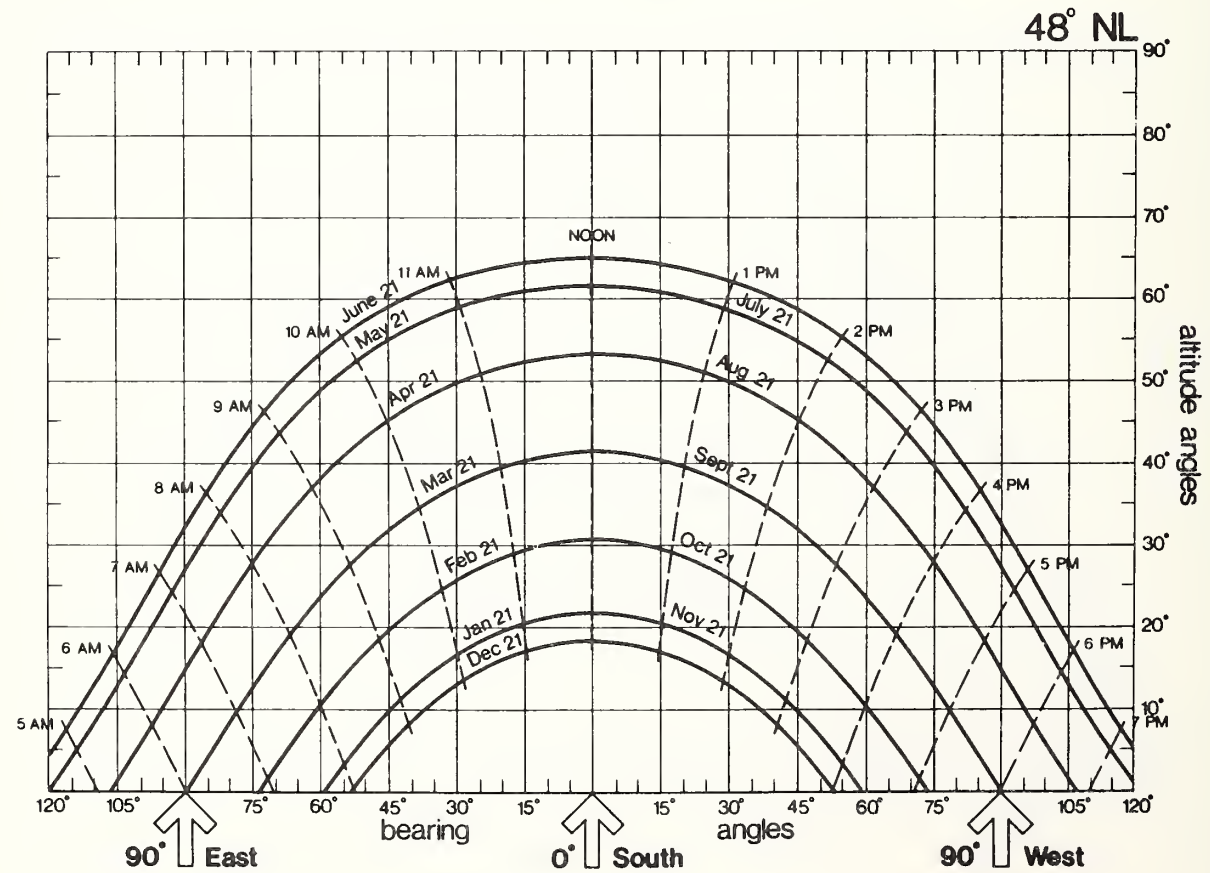





36° NL
NOON
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
altitude angles
90° 80° 70° 60° 50° 40° 30° 20° 10°
120° 105° 75° 60° 45° 30° 15° 15° 30° 45° 60° 75° 105° 120°
bearing
angles
90° East
0° South
90° West


40° NL
NOON
11 AM
1PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
altitude angles
90° 80° 70° 60° 50° 40° 30° 20° 10°
120° 105° 75° 60° 45° 30° 15° 15° 30° 45° 60° 75° 105° 120°
bearing
angles
90° East
0° South
90° West


44° NL
NOON
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
altitude angles
90° 75° 60° 45° 30° 15° 0° 15° 30° 45° 60° 75° 90°
bearing
angles
90° East
0° South
90° West


48° NL
NOON
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
June 21
May 21
Apr 21
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Oct 21
Nov 21
altitude angles
90° 75° 60° 45° 30° 15° 0° 15° 30° 45° 60° 75° 90°
bearing
angles
90° East
0° South
90° West

SYSTEM SIZING

Matching the size of a solar domestic hot water system to the water heating demands of the customer is critical. It is not sufficient to say that the average family uses 20 gallons of hot water per day, as each family's needs differ.

There are numerous accepted methods for the sizing of SDHW systems which range from simple mathematical calculations to elaborate computer programs. For each installation, three basic sizing calculations must be carried out: the water heating load, the total collector area, and storage size.

LOAD CALCULATIONS

The first step is to determine the amount of hot water (and its temperature) consumed annually. A water meter on the hot water line (or a KWH meter for an electric system) provides the most accurate record. Without a water meter, you can determine consumption by recording daily water use patterns.

AVERAGE HOT WATER CONSUMPTION

Clothes Washing	**14 lb. machine**	**18 lb. machine**
Hot wash / Hot rinse	38 gal	48 gal
Hot wash / Warm rinse	28 gal	36 gal
Hot wash / Cold rinse	19 gal	24 gal
Warm wash / Cold rinse	10 gal	12 gal
Dishwashing	**small**	**large**
w/ machine	10 gal	15 gal
w/out machine	4 to 8 gal	
Personal Hygiene		
Tub bathing	12 to 30 gal	
Wet shaving / hair washing	2 to 4 gal	
Showering	2 to 4 gal/minute	

Look for additional hot water loads such as photographic dark-room use.

This is a sample load calculation for a family of two adults and two children:

Food preparation for 2 meals per day	6 gal.
Hand and face washing	17
One dishwasher load per day	15
One laundry load per day	15
Three low-flow showers per day	30
One shave	3
Total	86 gal/day

Since the average household uses about 20 gallons per person per day, this sample family is close to average. If they took baths rather than showers, ran the dishwasher twice per day, and did two loads of laundry per day, their demand would change.

The next step is to convert the demand from gallons to Btu's. A Btu (British thermal unit) is the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit. There are 8.33 pounds of water in a gallon.

The total load calculation now requires two additional sources of information: the average annual temperature of hot water. As an example, use an incoming temperature of 50°F, and a domestic hot water temperature of 120°F, for a temperature difference (ΔT) of 70°F.

The calculations are:

86	gal/day
× 365	days
31390	gal/year
× 8.33	lbs/gal
261478	Btu/°F rise
× 70	ΔT °F
18303509	Btu per year, or 18.3 MBtu per year

Consider also the efficiency of the system.

Electric systems are about 70% efficient, including tank and pipe losses. So:

18.3	MBtu
× 1.3	
23.79	MBtu

Oil-fired systems (tankless coils) are roughly 40% efficient, including combustion loss, flue loss, jacket loss, and transmission loss. So:

18.3	MBtu
× 2.5	
45.75	MBtu

Gas systems are about 50% efficient. So:

18.3	
× 2.0	
36.6	MBtu

To determine what the family is spending on water heating, convert the figures to:

Electric: $\frac{23.79 \text{ MBtu}}{3413 \text{ Btu/KWH}} = 6970 \text{ KWH/yr.}$

Oil: $\frac{45.75 \text{ MBtu}}{135{,}000 \text{ Btu/gal}} = 338 \text{ gal/yr.}$

Gas: $\frac{36.6 \text{ MBtu}}{1000 \text{ Btu/cu ft}} = 36600 \text{ ft}^3\text{/yr.}$

*(**Note:** Sometimes the back-up heating will be converted from oil to electricity. Use the oil figures for calculating cost savings and electric figures for sizing.)*

COLLECTION AREA

Most collector manufacturers have reliable data on the output (in Btu's) of their collectors. Heat exchangers, storage size, and specific system design all affect output by as much as two to one. Collector performance is only one part of the whole system's efficiency.

If figures are not available from the manufacturer, you may perform your own calculations by referring to the insolation data for your area and your collector's efficiency curve. Insolation charts are available from ASHRAE and from local weather bureaus. Determine the average annual operating efficiency of the collector (for the application); then use the insolation figures to calculate how many Btu's will strike the collector. Remember to consider system losses. The result will be the Btu's which will be converted into useful heat.

For example, in a system with electric backup, the given demand is 23.79 MBtu per year. The manufacturer's data indicates that the collector will provide 6 MBtu per year when mounted at a tilt angle equal to the latitude for your geographic location, when a final temperature of 120°F is desired. This figure will not include tank, pipe, and heat exchange losses, so subtract 20% from the figure (assuming an insulated tank). Therefore, the effective system output for a 4′ x 6′ collector is 4.8 MBtu per year.

You may now calculate that a three panel system will provide approximately 14.4 MBtu per year, or 60% of the demand. A four panel system will provide 19.2 MBtu per year, for a solar fraction of 80%. Remember to include any shading or orientation losses into these calculations.

STORAGE SIZING

Storage tanks must be sized to provide 1.25 to 2.00 gallons per square foot of net collector area. Unbalanced systems either

produce large quantities of lower temperature water or higher than necessary temperatures which in turn, lowers collector efficiency.

Consult collector manufacturer's data concerning recommended storage sizes. On the average, a system consisting of three 20ft² collectors should have about 120 gallons of storage, if the water use temperature is to be from 120° to 140°F.

If higher temperatures are needed such as 180° for a commercial dishwasher, temperatures may be increased by reducing storage. By generating the higher temperatures, collector efficiency suffers. It is advisable to keep the 120° storage and boost the temperature to 180° with a separate heater.

ENERGY CONSUMPTION CHART

This chart explains the energy use of a family of four in the northeast. The average family consumes 20.7 million Btu's of energy per year.

This is determined in the following manner:

- *1 person uses 20 gallons of hot water per day.*
- *4 people at 365 days per year = 29,200 gal/yr. NOTES: A Btu is the amount of heat required to raise one pound of water by 1°F. Each gallon of water weighs 8.33 pounds. Therefore . . .*
- *243,236 Btu's per each degree of temperature rise are used.*
- *Water must be heated an average of 85° to reach the proper temperature.*
- *85 × 243,236 = 20.7 million Btu's.*

Overall System Efficiency
System losses and transport losses raise the total Btu usage above the minimum 20.7 million per family.

Electric Hot Water:
Electric water heating is nearly 100% efficient. However, 30% of the total energy required is lost through tank and pipe losses. Therefore average electric systems use 20.7M + 1.3 = *26.9 million Btu's per year.*

Oil Heated Water:
Oil fired tankless water heaters are roughly 30%–40% efficient. This figure includes combustion loss, jacket loss, flue loss, and transmission loss. Therefore average oil systems use 20.7M + 2.5 = *51.75 million Btu's per year.*

Gas Heated Water:
On the average, natural gas systems are 50% efficient. Therefore average gas systems use 20.7M + 2 = *41.4 million Btu's per year.*

Fuel Usage and Fuel Savings

- *One kilowatt hour of electricity supplies 3,413 Btu's.*
- *One gallon of #2 heating oil supplies 135,000 Btu's.*
- *1000 cubic feet of natural gas supplies 900,000 Btu's.*

Since solar water heating saves approximately 50% of the total water heating load, it will save the following amounts per year:

- *3,941 kilowatt hours of electricity.*
- *192 gallons of #2 fuel oil.*
- *23,000 cubic feet of natural gas.*

Actual Fuel Savings in Dollars

Electricity @ 3,941 KWH:

If cost/KWH is	You save
6.5¢	$256
8.5¢	$335
10.5¢	$414
12.5¢	$493
15.0¢	$591

Oil @ 196 gal:

If cost/gal is	You save
$1.30	$255
$1.50	$294
$1.70	$333
$1.90	$372

Natural Gas @ 23,000 cubic feet:

If cost/1000ft^3 is	You save
$6.50	$150
$7.50	$173
$8.50	$196
$9.50	$219

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Northeast Solar Energy Center
Solar Design Series
Design Note 2

What is f-Chart?

Ross Bisplinghoff

f-Chart is a design tool used for calculating the fraction of total energy heat load (f) supplied by an active solar-heating system.

Solar Systems

There are several kinds of systems that accept and transform sunlight into heat energy. The common greenhouse, used for years to extend the growing season for plants, is an example of a solar heating system. Because the greenhouse has no moving parts, it is called a "passive" system. Private residences and commercial buildings, today, are being heated by means of passive solar design, featuring south-facing windows, plenty of attic and side-wall insulation, and/or large thermal-mass heat storage (usually a thick, concrete slab or a large expanse of cinder or concrete-block wall).

Passive design concepts for residences are not new. The Pueblo Indians used passive solar concepts in the construction of their "houses". They built their houses into the sides of mountains, thus making use of direct gain and inherent thermal storage.

Another type of solar system, which is coming into increasing use, is the "active" solar system for producing domestic hot water and space heat. This system is called active, because it usually consists of a solar collector through which a heat-transfer fluid is circulated by mechanical means.

Solar Collectors

The recent surge of interest in active systems for domestic hot water and space heating has resulted in the widespread use of flat plate collectors. As a matter of fact, when the term "solar energy" is used, most people associate it with flat-plate collectors.

This type of collector is usually made of a black, flat metal plate over which either air or liquid flows. With traditional flat plate collectors, as shown in Figure 1, the absorbing plate is

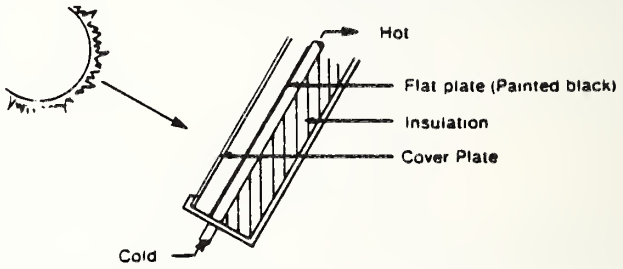


Figure 1. Simple flat plate collector.

heated by the sun shining through a transparent cover. The sun's rays are absorbed by the black plate, and the fluid is heated. An insulated backing and the cover minimize the heat loss.

The solar collector is usually connected to an energy storage unit, either a water tank or, in the case of an air collector, a pebble bed, so that excess heat can be stored for later use. When the

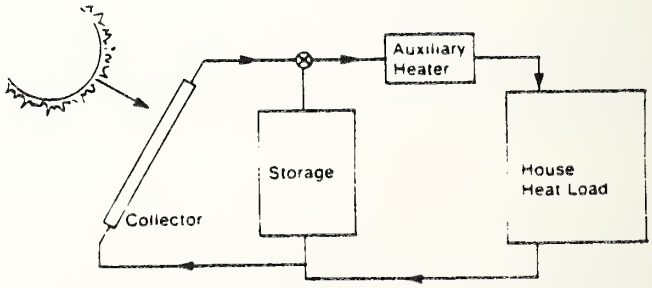


Figure 2. Typical solar heating system.

heat produced by solar energy is insufficient to meet the needs of the house, an auxiliary heater supplies the deficit. Figure 2 shows a typical solar heating system. The sun heats the transfer fluid in

the collector, which circulates directly into the storage unit. Then heated water or air goes to the heating system or hot water tap. If more heat is required than the collector can provide, the auxiliary heater turns on at a preset temperature to supply the balance. While this system seems simple, a question arises: How large a system is necessary to supply the hot water or space heating needs?

The f-Chart Method

The f-Chart solar heating design method enables the designer to answer that question. It is a practical calculation method which considers the performance of various component parts of the active solar system, such as, the solar collector, the energy storage unit, the auxiliary heater and the heating load. The f-Chart method can predict the most economical design of a solar heating system; it can predict monthly, yearly and long term performance of the system; and it can provide a detailed cash flow analysis of the solar system costs and savings.

History

The f-Chart method, originally developed in 1974 at the University of Wisconsin, evolved from a compilation of detailed computer runs, using the University's computer program, TRNSYS, which simulates all elements of a solar system. This evolution stemmed from the need for a simplified design procedure for use by the heating industry to estimate the performance of standard types of solar systems. TRNSYS simulations were too complicated and too costly. The approach was to identify key dimensionless variables and to use the detailed TRNSYS simulations to correlate these variables with the long-term performance of the standard systems. The correlations, developed for liquid and air heating systems and for domestic hot water systems, were presented in the form of graphs called "f-Charts". These f-Charts are the basis of a simple method requiring monthly meteorological data to estimate the long-term thermal performance of solar heating systems.

Organization and Purpose

f-Chart is made up of two parts: a thermal performance section, which determines the heat output of a solar system by month and compares it to the heat requirements of the load; and an economics section, which simulates cash flows for several economic parameters on a yearly basis.

With the f-Chart method, architects, engineers, builders and laymen can easily determine the thermal performance of solar heating systems and optimize their performance based on the cost of the system.

The Systems Modeled

The f-Chart method can model three different types of active solar heating systems:

- Liquid or air domestic hot water heating
- Liquid space and domestic hot water heating
- Air space and domestic hot water heating

Each of these systems uses a flat plate collector to heat the heat transfer medium.

The first system, liquid or air domestic hot water heating, is shown in Figure 3 as a liquid domestic hot water system. This system is now

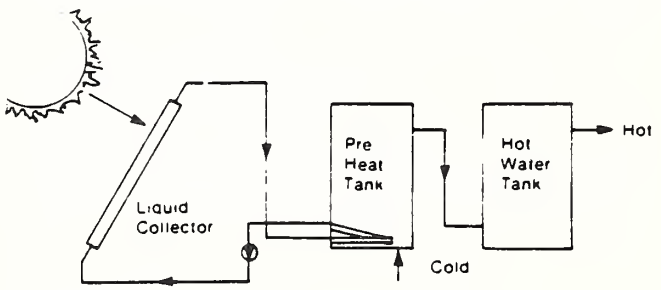


Figure 3. Liquid domestic hot water system.

quite common throughout the country, and f-Chart is frequently used to calculate its performance. The system consists of solar collectors, a solar preheat tank and the standard home hot-water tank. Liquid or air flows through the collectors, is heated by the sun, and goes through a heat exchanger in the preheat tank, warming the cold water coming from the house's water main. The water then flows through the hot water tank, picking up any additional heat, as needed, before it goes to the house's hot water taps. This is the simplest system that f-Chart models, and, it allows the user to adjust or optimize many design parameters and predict the system's thermal and economic performance.

The second system, liquid space and water

heating, illustrated in Figure 4, is a little more complicated than the first. This system has two thermal loops that supply heat; one is for

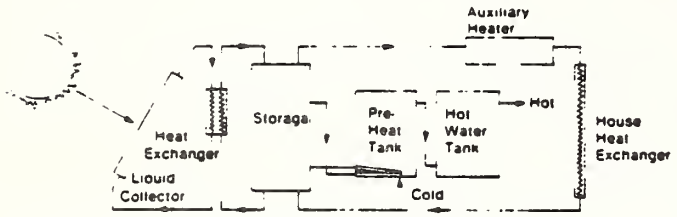


Figure 4. Liquid space and water heating system.

domestic hot water, the other is for space heating. A heat transfer liquid flows through the solar collectors where it is heated; it then gives up this heat by means of the heat exchanger to water which is used as the heat storage medium. The hot water is used to heat the domestic hot-water supply just as in the liquid solar hot water system. The solar-heated water can also heat the house by flowing through convectors, or by indirect heat exchangers.

The third system, the air space and water heating system, is shown in Figure 5. This system is basically the same as the liquid-based version except that air is used as the heat transfer fluid and rocks instead of water are used as the heat

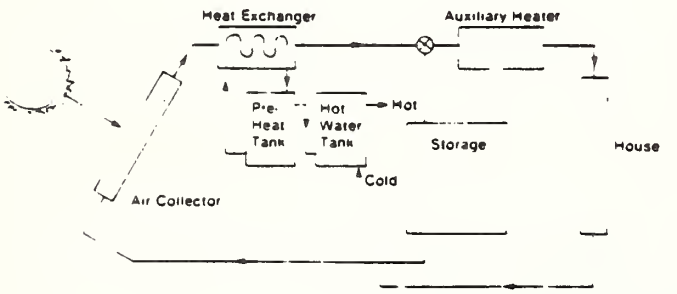


Figure 5. Air space and water heating system.

storage medium. Air heated in the collector flows through the domestic hot water heat exchanger and heats the water in the preheat tank. The hot air then flows either into the thermal storage unit or into the house. The damper, X, allows hot air to enter the house from the collectors, from storage, or from both. If there is still insufficient heat to meet the house load, the auxiliary heater turns on automatically at a preset temperature to supply the difference. The return air circulates back through the collector and is again heated. Note that air heated by the collector directly heats the house. This is less complicated than liquid space heating because a heat exchanger is not needed.

Pumps and blowers are not drawn in the diagrams of the systems in order to simplify the drawings.

Predicting Thermal Performance

To predict the thermal performance of any system described above, the operating characteristics of the system must be specified. The efficiency of the collector, its orientation to the sun, sizes of component parts, and heat flow rates must be known or calculated in order to predict the system's performance using the f-Chart method. An essential piece of information is how efficiently the collector performs. Usually performance is described by a collector efficiency curve which is measured experimentally by standard collector tests. A description of the efficiency curve and how it is used is the subject of NESEC Design Note 1.

The domestic hot-water use rate must be estimated if a hot-water heating system is being modeled, because the heat produced by the solar system must be compared to that required to heat the hot-water supply. The ratio of comparison is referred to as the "solar fraction", which is defined as the amount of *solar* heat delivered to the hot water supply divided by the *total* heat required for the domestic hot water.

For a space heat system, the heat load must be calculated to determine the proper size of the solar system. In this case, the solar fraction is defined as the amount of solar heat delivered to the house divided by the total heat necessary to keep the house at its design temperature.

Once all of the system characteristics are defined, the f-Chart analysis is made using solar and meteorological data from the closest local weather station which has this data available. The amount of solar heat delivered by month is calculated along with the amount of heat required by the load (whether the load is hot water or space heat). The ratio of these numbers yields the solar fraction, calculated by month and then averaged for the year. The f-Chart method can be used for

almost any size system in any location where meteorological and solar data are available.

Predicting Economic Performance

To predict the economic performance of a solar system, certain system characteristics must be specified. The heating cost using the existing conventional heating system must be known. This allows a cost comparison to be made between the existing system and the solar system (with a backup conventional auxiliary heater). The initial cost of the solar system along with any finance payments must be specified because a yearly cash flow analysis is done which shows costs incurred by the purchase of the solar system and costs incurred from auxiliary fuel for the backup heating unit. Income and property taxes, along with insurance and maintenance costs, can also be included in the cash flow analysis. In its entirety, the f-Chart economic analysis generates yearly cash flows for 10 economic parameters describing the solar system. It also can be used to determine the optimum system size which maximizes the life cycle savings. In other words, f-Chart can determine the most economical size system.

How the f-Chart Method Is Used

f-Chart calculations can be performed by using a variety of techniques. In *Solar Heating Design by the f-Chart Method*, Reference 1, the authors discuss the f-Chart method in detail and provide worksheets for doing the calculations by hand. The procedure is long, involved, and tedious and is not suitable for making many analyses of one system to determine which design looks the most promising. Because of this, an interactive computer program called FCHART was developed at the University Wisconsin. It enables the user to sit at a computer terminal and answer questions the program asks about the solar system he wants to model. This popular technique has one disadvantage. The user needs access to a computer. Another widely used technique is the FCHART type programs written for hand-held programmable calculators which are available from several companies. The technique allows an individual or company, for a relatively small investment, to buy and run the program. Finally, there is a technique that makes use of graphs which apply to solar DHW systems operated over a range of conditions in the Northeast. With six graphs, the user can predict DHW system performance in a matter of minutes. The details of the method and graphs for use throughout the Northeast Region are presented in Design Note 4.

The FCHART Computer Program

The FCHART interactive computer program, developed in 1976 at the University of Wisconsin Solar Energy Laboratory, is a continuation of the work done on the basic f-Chart design method. It is quite easy to use, even by people with little or no exposure to computers. The program is called "interactive", because it asks the user what type of program descriptions and information the user would like to see and then proceeds to ask questions about the characteristics of the system to be modeled. The program lists a set of input variables along with default values which have already been stored in the program. The user modifies this list to describe accurately the particular system that he is interested in modeling and then runs the program to perform the analysis.

The FCHART output consists of two sections, i.e., thermal analysis and economic analysis. The thermal analysis includes temperature, degree days and incident solar energy for the solar system location by month, hot water load and space heating load by month, and the solar fraction, or the percent of the total load, supplied by solar energy for each month. The economic analysis includes the collector area, initial cost of the solar system, the annual mortgage payment, the years until the mortgage principal equals the solar savings, the present value of solar savings and cash flows by year for ten different economic output parameters. The analysis can also determine the optimum collector area relative to the present value of cumulative costs of the complete solar-assisted system.

FCHART Domestic Hot Water Example

To illustrate the use of the FCHART computer program, a domestic hot water system example is presented. The following table lists the pertinent characteristics of the system.

Typical Solar Domestic Hot Water System

Location	Boston
Collector Area	72 ft² (3 panels)
Hot water load	71 gal/day (50°F-130°F rise)
Glazing #	1
Slope	45°
Azimuth	0°
$F_R,(\tau\alpha)$	0.71
F_R,U_L	1.04
Cost	$1480 ($2500-$1020 with HUD and IRS tax incentives)
Mortgage term	20 years

These characteristics are input to the program after responding to the questions shown in Fig. 6. A listing of our typical system's thermal and economic variables is given in Fig. 7. The thermal and economic analyses are run by typing "R" and the results are displayed in Fig. 8. Note that the solar fraction which is listed as "percent solar" in the figure is 53.5 percent for the year. In the economic analysis, the yearly mortgage payment is $167 and the rate of return on the solar investment is 34.5%.

Summary

It is possible to predict the long term thermal and economic performance of flat plate solar collector systems using the f-Chart design method. The method utilizes a variety of techniques. the most widely used today being the FCHART computer program. The inaccessibility of a large computer to interested users has lead to the development of FCHART calculator programs and simplified graphical techniques providing a wider audience the means for estimating performance.

This Design Note has been written to provide a broad overview of the f-Chart calculation method. For more detailed information on the f-Chart method refer to *Solar Heating Design*, Reference 1, and the *FCHART Users Manual*, Reference 2.

References

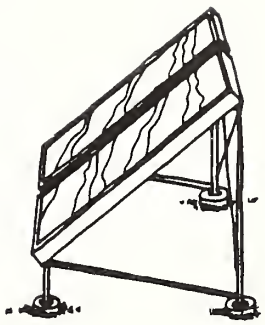
1. Beckman W.A., Klein, S.A., Duffie, J.A., *Solar Heating Design by the f-Chart Method*, Wiley & Sons, New York, 1977.

2. Hughes, P.J., Buckles, W.E., Klein, S.A., *FCHART Version 3.0 Users Manual*, 1978, distributed by Solar Energy Research Institute, Golden, Colorado, 80401.

This Design Note was prepared by the Systems Design Department of the Northeast Solar Energy Center to promote the application of solar energy in the Northeast. For further Information, contact the Center at 70 Memorial Drive, Cambridge, Massachusetts, 02142.

CHAPTER FOUR

Collector Mountings



This chapter takes you step-by-step through proper procedures for mounting collectors on a roof, making the necessary penetrations, and for installing ground-mounted collectors.

GENERAL CONSIDERATIONS

Wind Loads

According to HUD's Intermediate Minimum Property Standards (IMPS) and the National Bureau of Standards, the mounting structure should be built to withstand winds of at least 150 mph. Flat-plate collectors mounted flush with the roof surface should be constructed to withstand the same wind loads.

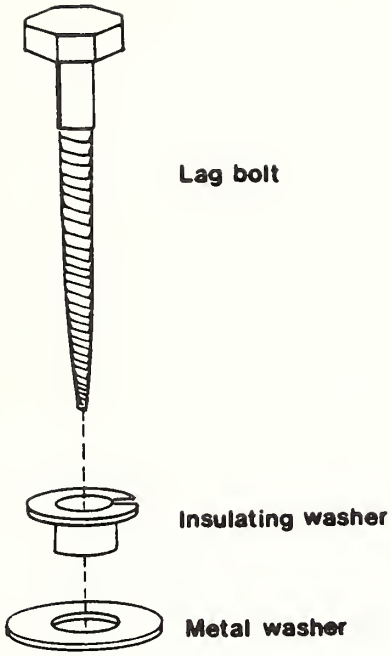
When mounted on racks, the collector array becomes more vulnerable to wind gusts as the angle of the mount increases. Collectors can be completely uplifted by wind striking the undersides. This wind load, which is in addition to the equivalent roof-area wind loads, should be determined according to accepted engineering procedures.

Snow Loads

Collectors mounted flush on a roof should be designed to support the snow loads which may occur on the roof area they cover. The collector array should be installed at greater than 35° to expedite snow sliding. Plastic and fiberglass glazing (FRP) clear snow faster than glass does. Collectors with complex configurations, such as evacuated tubes and concentrators, may have problems with snow collecting on their irregular surfaces.

The roof structure should be free of objects which might retard snow sliding. You should also consider installing snow belts (or snow slides) beneath the collectors. Collectors mounted on elevated racks or in sawtooth patterns may create snow drifting

on the roof in addition to normal snow loads. What is critical is that snow and ice build-up will not become hazardous to either people or to the structure.



Corrosion Protection

Both roof-mounted collector arrays and mounting hardware (bolts, screws, washers, angles) must be carefully protected from corrosion. Steel mounting hardware which comes in contact with aluminum and copper piping or with aluminum hardware are examples of high corrosion-potential combinations. Cadmium-plated or hot-dipped galvanized bolts can be used to mount collectors on racks.

The exposed edges of all galvanized steel should be protected with a zinc chromate paint. Heads of bolts should be coated with silicone to retard corrosion, and dissimilar metal should be separated by washers made of teflon, nylon, or neoprene. Most collectors manufacturers or distributors are able to supply the specialty mounting hardware needed to do a professional installation. Follow their instructions carefully, and be sure to cover all holes and mountng assemblies with a high quality sealant.

ROOF CONDITIONS

See that the roof surface is in good repair before mounting collectors. If there is a need for reshingling or other repair work, the work should be done before mounting the collectors. Keep future roof repair and maintenance in mind when planning collector mounts. Easily removable collectors will make such work easier.

Important Note: *Do not mount collectors on roofs that are in need of repair without getting a written statement from the homeowners that they are aware of the condition, they desire the work to proceed, and they directly waive all responsibility for roof damages.*

PRECAUTIONS FOR WORKING ON ROOFS

One should plan mounting procedures carefully to minimize the number of trips over the roof. Walk carefully on gravel roofs. They are more fragile than they appear, and the source of a leak in a gravel roof is not easy to locate. Lay planks or plywood to walk on in heavy traffic areas. Wood-shake and clay tile roofs are very brittle. Be very careful walking and do not drop your tools. Use a lifeline on any steep roof.

Specially designed roofer's shoes are recommended on asphalt shingle roofs. Shoes with heavy lug soles should be avoided because they can damage shingles, especially in warm weather.

HOISTING ROOF-MOUNTED COLLECTORS

A typical collector weighs between 75 and 200 pounds. The

careful installer should plan well in advance how to hoist the collectors to the roof. To lift the collectors manually is possible, but it will require at least two strong people. One method is to use two parallel ladders with two people walking one collector up at a time. If the collector is outfitted with flanges, temporary handles may be attached.

The so-called "Push and Pull" method uses one ladder as a steep inclined plane. A rope is attached to one end of a collector A person on the roof hoists the collector while a partner lifts and guides it up the ladder to prevent it from swinging out of control.

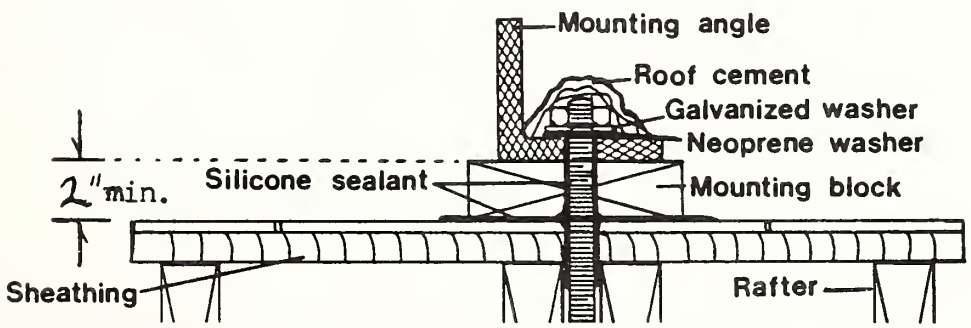
POSITIONING COLLECTORS

Be sure the collector array is sloped 1/8-inch per foot. Measure the distance from the top of the collector array to the ridge line at each end and check with a bubble level. A chalk line makes a useful guide. Slope the array toward the inlet to facilitate drainage at the minimum rate of 1/8-inch per foot. Draindown and drainback systems require additional pitch, so be certain to follow manufacturer's recommendations. Allow at least 1/4-inch spacing between collectors for expansion and contraction which could loosen the mounting.

Collectors with weep holes must be mounted with weep holes at the bottom. They allow moisture to escape as condensation can damage insulation values as well as some absorber surfaces. Holes should be loosely blocked with fiberglass which will prevent the entry of dirt or insects while still allowing a flow of air.

INSTALLING SPACERS

On retrofit installations, collectors should be raised at least 2 inches above the roof to avoid damage to shingles. Without that



space, moisture buildup could cause growth of fungus, mold, and mildew. Ice dams could also form and draw water under

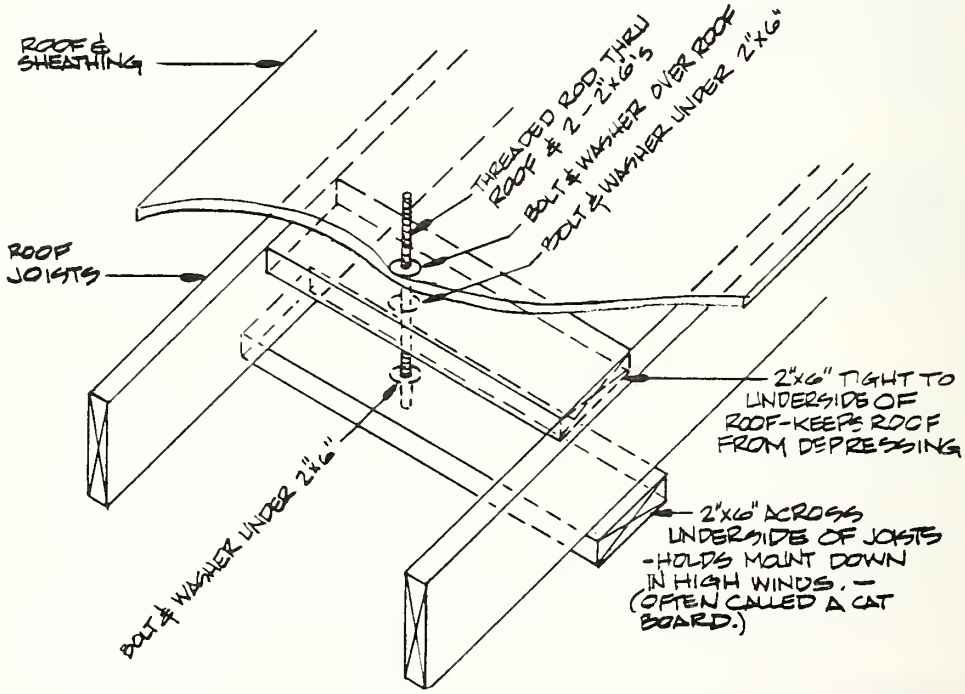
shingles by capillary action. These factors contribute to roof surface deterioration.

Spacer blocks of acrylic, aluminum, galvanized steel, or rot resistant wood should be used between the collector and the roof surface. If wood is treated with a wood preservative, it should be checked because some preservatives may dissolve asphalt roofing materials. A silicone sealant or fibrous roofing cement should be applied between the roof and spacer blocks and around all fasteners.

Instead of a block spacer, a mounting angle or clip can be used. It should be made of a metal compatible with the metal of the collector box. Fasten it directly to the collector box or flange and bolt it to the roof with a compatible fastener.

SPANNER MOUNTING

A spanner mount is recommended if the attic is accessible. Spanner mounts evenly distribute the uplift force of wind on the collector array to the roof framing members. Screw or nail 2 x 4 spanners directly to the rafters inside the attic, perpendicular to the rafters. Two spanners should be used. Pre-drill holes through the roof and mount spacers large enough to accept the thru-bolts. Be careful not to split the spacers. It may be easier to drill holes and insert thru-bolts before securing spanners to assure proper alignment of holes.


ROOF & SHEATHING
ROOF JOISTS
THREADED ROD THRU ROOF & 2-2"x6"'S
BOLT & WASHER OVER ROOF
BOLT & WASHER UNDER 2"x6"
2"x6" TIGHT TO UNDERSIDE OF ROOF-KEEPS ROOF FROM DEPRESSING
2"x6" ACROSS UNDERSIDE OF JOISTS -HOLDS MOUNT DOWN IN HIGH WINDS.- (OFTEN CALLED A CAT BOARD.)
BOLT & WASHER UNDER 2"x6"

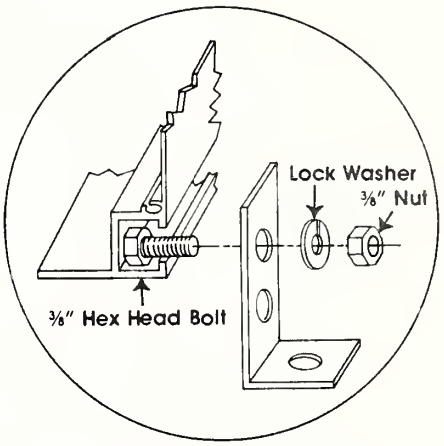
Thru-bolts or threaded rods should be at least 3/8 inches in diameter. Two nuts and large-diameter (fender) washers are recommended on both ends of the threaded rod. Silicone sealant should be applied generously to holes and between washers and mounting blocks. Use neoprene washers in conjunction with

metal washers to minimize risk of leakage. Be sure that the holes contain enough sealant to prevent leakage. Sealant should ooze liberally from around bolt heads when they are tightened down.

After bolt heads are tightened, apply more sealant over the heads and mounting block or clip assembly. If roof cement is used rather than silicone, the fibrous type is recommended because the weatherproof seal remains intact.

SPANNER MOUNTING IN A CONCEALED ATTIC

To insure a lasting installation, it may be worthwhile to cut sheetrock to expose rafters and repair it later. Nail wood blocks to the inside of the rafters at least 3 inches short of the ceiling edge. Fasten the spanners on these blocks. Use threaded thru-bolts as described above, seal, and bolt. Replace gypsum board to cover the installation.

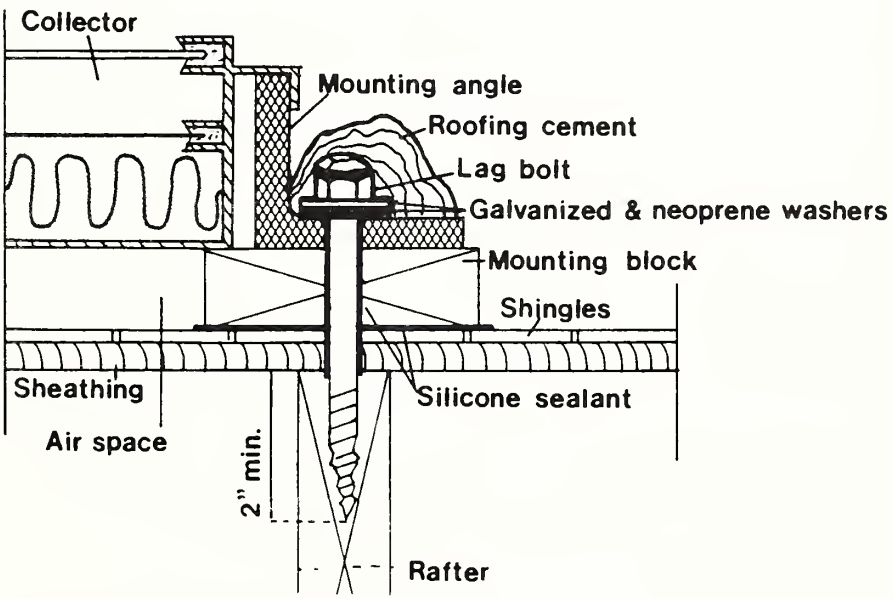


Integral Mounting Channel Detail

LAG BOLT MOUNTING

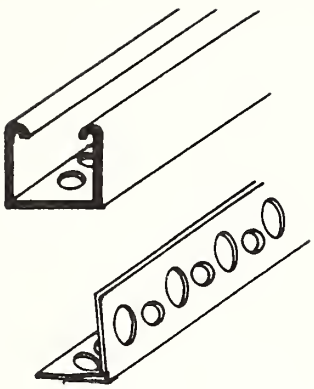
Collectors or the mounting racks can be lag bolted directly to the roof from the outside. Lags must be fastened to rafters or trusses rather than to sheathing so wind cannot pull them free.

Rafters or trusses can be found by carefully lifting a row of shingles and nailing under the shingle. Find both sides of the rafter so that the bolts will be centered. Drill holes through the roof several sizes smaller than the bolt to assure a tight fit. The lag bolt should penetrate the rafters by at least two inches.



Insert the lag bolt through a metal washer and then through a neoprene washer before going through the collector flange and mounting block. Be sure to apply a liberal quantity of sealant to the holes and between mounting blocks, washers, and the roof surface before tightening down lag bolts. After mounting, apply more sealant over the entire assembly. This method is more

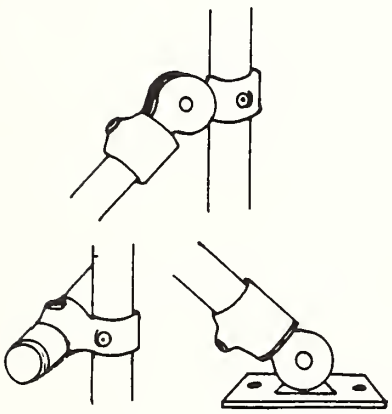
completely explained in "Roof Mounting Step-by-Step," by Jack Meeker and Larry O'Keefe which is reprinted at the end of this chapter.



RACK MOUNTING

Collectors can be mounted on racks or stand-offs to achieve the optimum tilt angle. If the holes or clips on the collectors do not line up with rafters or trusses, you may mount the collectors on a rack, then properly fasten the rack to the framing members.

The rail should be at least 12 gauge and about 1½ x 1½ inches in dimension. Slotted angle rail, normally used to fabricate warehouse shelving, is readily available and can be cut to any length and bolted together. The collectors should be bolted to the rail framework. Take care to prevent galvanic corrosion. The framework is lag-bolted or spanner-mounted to the roof, and roof penetrations are carefully sealed. Most collector manufacturers have racking systems which they have either designed or approved. Many collectors have perimeter mounting channels which allow for attachment of rack supports at any point. Several manufacturers have developed universal racks which offer the installer both flexibility and speed of installation.

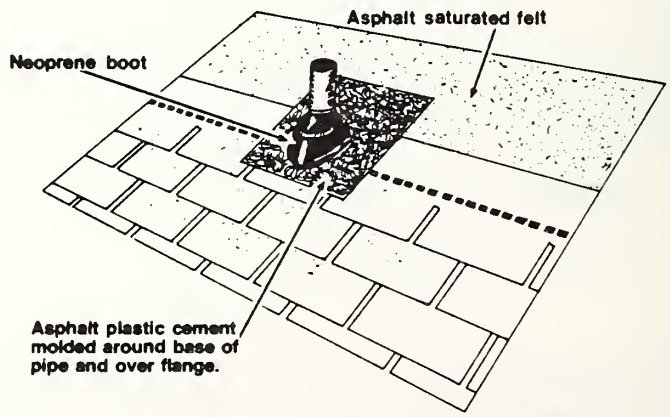


PIPE MOUNTING

Some collector mounting approaches use one-inch galvanized pipe and fittings used in awnings, or there is a pipe and fitting system called Speed-Rail®, which is secured with set screws. The pipe framework can be welded or bolted to 3/8-inch corrosion-protected steel support plates and fastened to the roof.

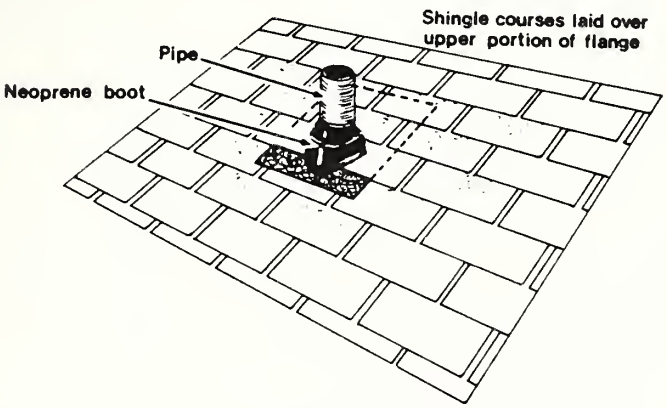
ROOF PENETRATION FOR PIPES

It usually is necessary to run pipes as well as fasteners through the roof surface. Keep the number of penetrations to a minimum. Pipes are flashed using the same methods as vent pipes or soil stacks. The most common way is to use a roof flange.



Roof flanges are readily obtained from roofing or building supply stores. Common sizes range from 1¼ to 4 inches. They

are available in galvanized steel, aluminum, neoprene, or copper, and some have neoprene collars. The neoprene collar flanges do not require a sealant where the pipe passes through, and collars are adjustable to any roof pitch.



Select a roof flange that will make a tight fit over the pipe. Remember that pipe insulation also must pass through the roof. Coat the bottom of the flange with sealant before fastening to the roof surface. The top of the flange must be completely under the shingles and the bottom completely over the shingles. Apply more sealant between shingles and flange. If the insulation does not have a rigid casing, an alternative method is to insulate up to the penetration and use reducers and a plastic nipple for the penetration.

GROUND MOUNTINGS

If there is too little roof space or the roof faces the wrong direction, collectors can be ground-mounted. Ground mounts make installation easier by eliminating roof work, simplifying maintenance, and, in most cases, shortening the run from collectors to storage.

Footings

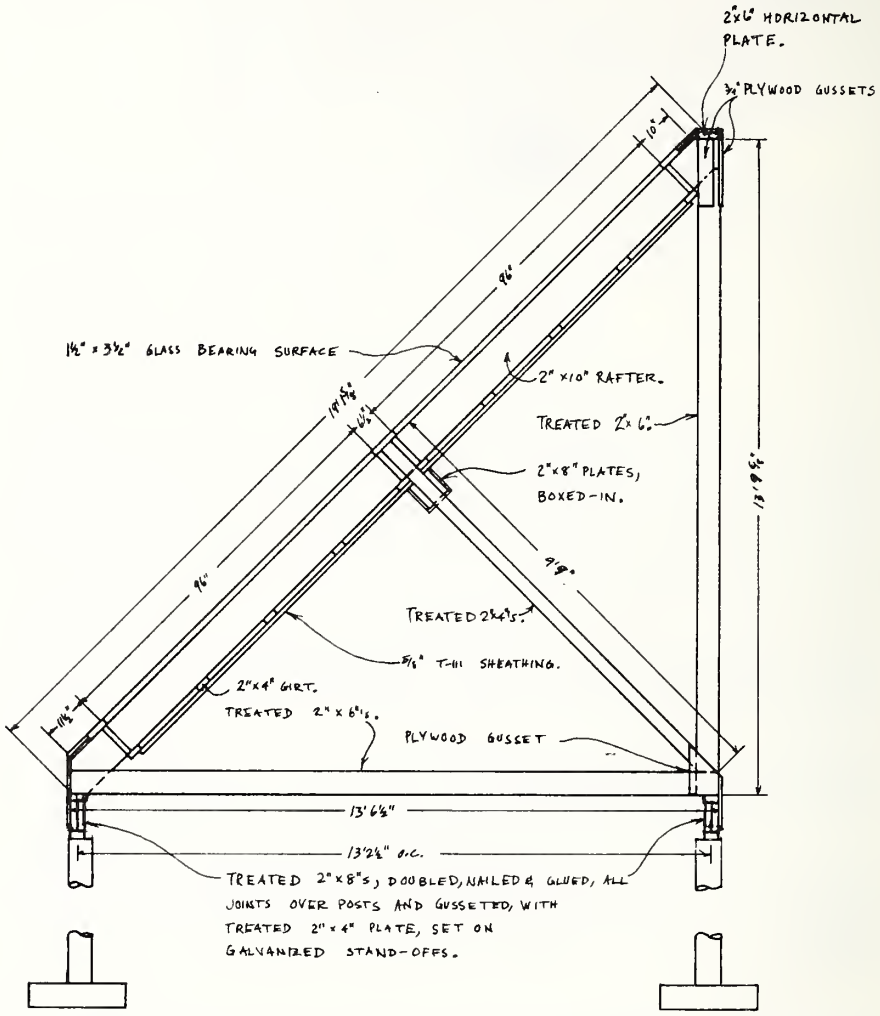
Collectors are mounted on a rack or frame that must be securely attached to footings extending below the frost line. There should be at least four pier footings, 8″ x 8″ square or 8″ in diameter. Footing holes should be dug below the frost line and the footings should be on undisturbed or well-packed ground. The footings should be poured with a frame member or a threaded rod protruding from the concrete.

If the frame is embedded, make a temporary jig so that the rack holds its shape while the concrete sets. If the frame member is wood, it must be pressure-treated. If you are using a threaded rod, it must be at least 3/8 inches in diameter.

Ground-Mounting Frames

The collector frame can be made from several materials: galvanized steel pipe, aluminum or steel angle iron, or wood.

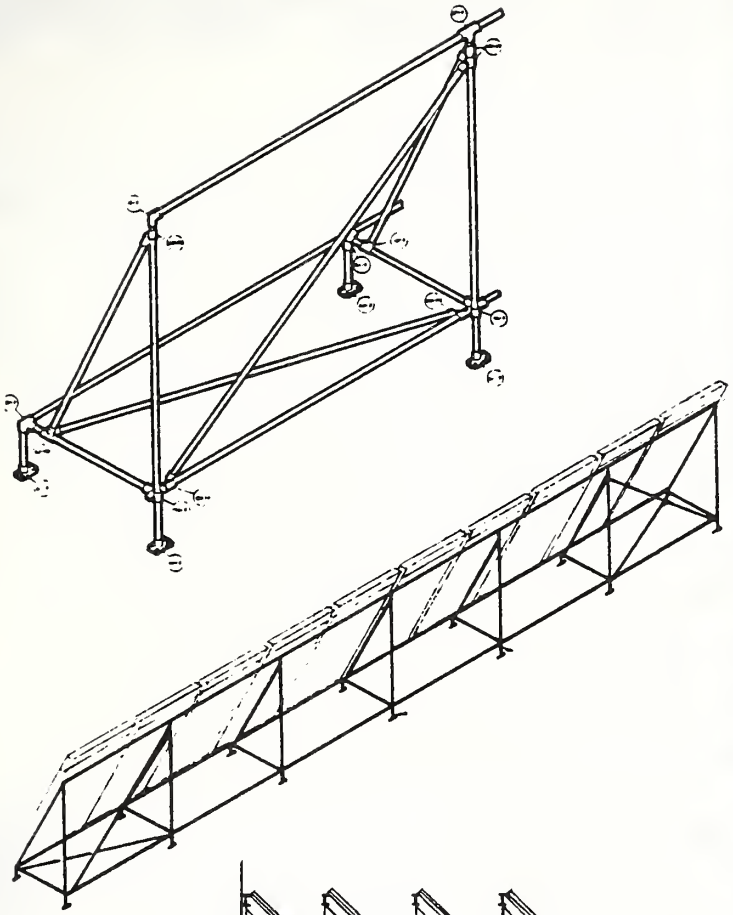
Galvanized steel pipe and fittings are readily available. If the collector boxes are aluminum, be certain to keep the steel and aluminum from touching each other to prevent galvanic corrosion. Slotted steel angle iron of at least 12 gauge and about 1½ x 1½ inches can be easily cut to any length and bolted together.

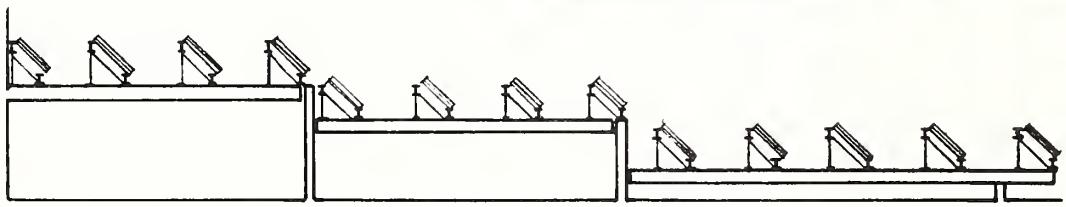

2"x6" HORIZONTAL PLATE.
¾" PLYWOOD GUSSETS
10"
96"
1½" x 3½" GLASS BEARING SURFACE
2" x 10" RAFTER.
TREATED 2" x 6".
2"x8" PLATES, BOXED-IN.
96"
TREATED 2x4's.
⅝" T-111 SHEATHING.
2"x4" GIRT. TREATED 2" x 6"'s.
PLYWOOD GUSSET
13'6½"
13'2½" o.c.
TREATED 2"x8"s, DOUBLED, NAILED & GLUED, ALL JOINTS OVER POSTS AND GUSSETED WITH TREATED 2" x 4" PLATE, SET ON GALVANIZED STAND-OFFS.

Careful attention must be paid to corrosion control. Aluminum angle extrusions will be lighter than steel angle iron and more corrosion resistant. They are also compatible with aluminum collector boxes. However, you can always expect aluminum standard shapes to be more expensive than steel. Wooden collector frames must be made of redwood, cedar, or treated wood to resist rotting, weathering, and insects.

FRAMEWORK REQUIREMENTS

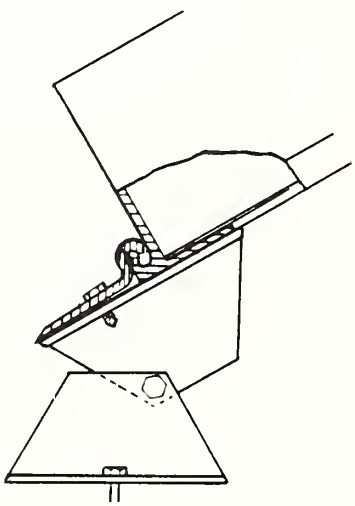
In addition to proper elevation and orientation, the bottom edge of the collectors must be a minimum of 18 inches off the ground to prevent mud splashing and snow drifting. A pebble bed in front of the collectors helps prevent erosion. Remember that the framework must be cross-braced and built to withstand the dead load of the collectors, live snow loads, and wind loads up to 100 MPH.





MOUNTING TECHNIQUES FOR FLAT ROOFS

On flat roofs, collectors can be mounted on uprights which are then fastened to the roof. The base of the upright is placed in a pitch container and both are simultaneously bolted onto the roof, by either the spanner or the lag bolt method. The container should have a lip to accept flashing, which is extended down onto the roof surface. The container is then filled with pitch or roofing cement. Pitch pots require frequent inspection and do not have lasting watertight qualities.



The National Roofing Contractors Association recommends use of curb mounts. A curb mount requires building up the roof surface with framing members to act as an equipment support. The curb is flashed into the roof surface and covered with a sheet-metal hood. The collector support is bolted through the hood and flashed into the curb. The NRCA recommends that curbs on flat roofs not span the whole roof so that water pockets do not develop.

Roof Mounting Step-by-Step

The preferred method for fastening collectors directly into roof rafters

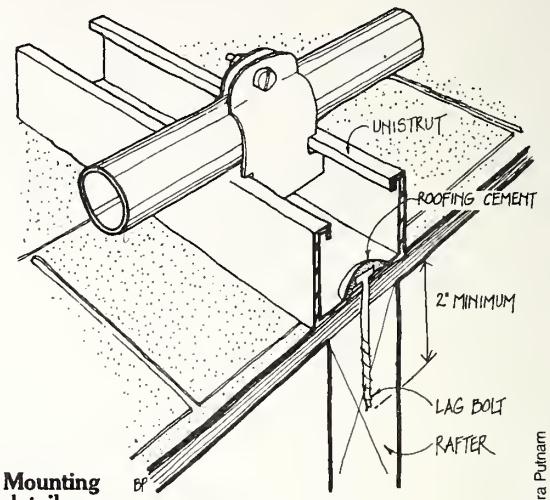
By Jack Meeker and Larry O'Keefe

In this mounting detail for shingled roofs, sections of Unistrut (or equivalent) channels are lag screwed into the center of the roof rafters. The channels raise the horizontal pipe rack rails above the roof, so that water, snow, and debris can flow freely under the array. Galvanized pipe racks are clamped to the channels, and the collectors are clamped to the pipe rack.

An accurate drawing of the collector array and the piping route should be done before the actual installation takes place. This will prevent unnecessary cutting through the roof framing for the pipe headers which penetrate the roof, reducing installation time and costs.

Jack Meeker is an energy consultant in Wilmington, Mass., director and cofounder of the National Association of Solar Contractors, and lecturer at Northeastern University. Larry O'Keefe is executive vice president of Power Solar Engineering in Wakefield, Mass. He holds a B.A. in engineering from Northeastern University.

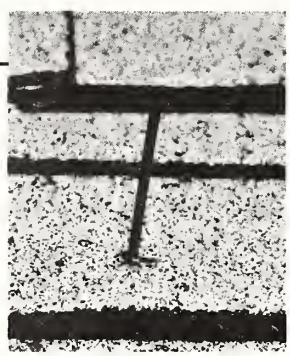
Photos courtesy of Power Solar Engineering and Jack Meeker.



Mounting detail

Barbara Putnam

1 **Array Perimeter:** *Chalk lines across the roof where the top and bottom of the collector array will approximately lie. Extend the lines at least two feet longer than the array.*



2 **Framing Location:** *If there is access to the attic, drive an 8d (8 penny) nail up through the sheathing, adjacent to each rafter, under the lines. On the roof, mark in red where the centerlines are thought to be. If there is no access to the attic, tap across the lines with a hammer. A solid sound should indicate the location of the framing.*

3 **Rafter Edges:** *Drive each nail back into the roof. Lift each shingle carefully to avoid tearing. Using 8d nails, locate the other edge of the rafter by nailing across the rafter until a nail penetrates the sheathing more easily. (With practice, fewer nails can be used.)*

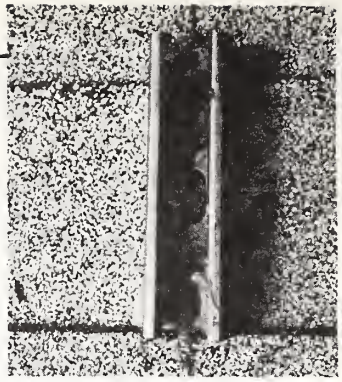
4 **Rafter Centerlines:** *Measure across the nails and locate the edges and centerlines of the rafters, and mark them in red. It is essential that the center of the rafters be found to prevent splitting and ensure a secure lasting mount. These steps* **must** *be done at the top and bottom of* **each** *rafter. Locating the four of five rafters under a typical SDHW array should only take 45 minutes.*

5 **Penetration Sealant:** *Do not remove the nails—leaking will occur—but caulk across the nailheads with silicone. Lay the shingles back over the nails, and caulk the holes where the nails penetrated from the attic.*

6 **Rafter Location:** *Snap a chalkline between each pair of rafter centerlines to identify the length of each rafter under the collector. This will set up a grid for fastening the mounting channels.*

7 **Pilot Holes:** *Place Unistrut (or equivalent) mounting channels over the chalk lines, and drill pilot holes into the center of the rafters for the lag screws—two per section. The bit for the holes should be two sizes smaller than the lag. Place each row of channels either above or below the area where the nails are, to avoid conflict.*

8 **Pilot Sealant:** *Apply silicone sealant into the pilot holes and press mounting channels in place, creating a waterproof bond.*



9 **Lag Screws:** *Lag the mounting channels into the pilot holes, with washers as shown in Figure 1 (5/16" × 4" lags for 2 × 6 rafters; 5/16" × 5" for 2 × 8 rafters). Silicone over the heads for a weatherproof seal.*

10 **Rack Rails:** *Attach galvanized pipe rack rails to channels, forming the collector rack. (Speed rail or equivalent may be used.) Fourteen gauge pipe clamps that fit into the Unistrut sections are available from Unistrut.*

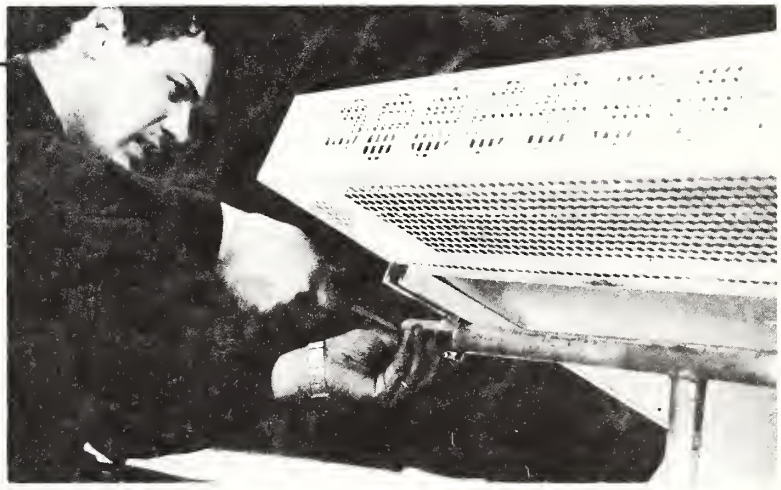
11 **Finished Rack:** *Fasten the upper rack to the rack rails. This particular prefabricated rack was welded together, but it could be made using standard pipe fittings. The rack should be pitched slightly to allow for drainage if collector service is required; in closed-loop systems (½-in. per 4 ft.) or in drainback or draindown systems (1 in. per 4 ft.).*

12 **Traverse Rack:** *If the roof does not face within 20° ± of true south, place the array at an angle to the ridge to achieve the proper orientation. Each mounting strut lies across at least two rafters per channel, to spread the load across the roof and afford at least two lags per channel section.*

13 **Collector Channel:** *Attach channel sections to the corners of the collectors. Make sure the particular collector can receive the screws without damage.*

14 **Collector Placement:** *Carry each collector to the roof and place on the rack. Notice that the collector face here is covered to prevent stagnation before the collector is plumbed.*

15 **Collector Fastening:** *Fasten each collector corner to the pipe rack with pipe clamps.*



16 **Pipe Penetrations:** *Using a 3-inch-diameter hole saw, drill holes for the feed and return pipes. Two saw bits will be required—one for the shingles (which will become too dull to drill for the sheathing), and one for the sheathing. The holes should be drilled outside the array to allow space for servicing. The 3-inch hole will be large enough to accommodate the 3-inch diameter insulation and a 2-inch No-Calk Roof Flange (commonly used for plumbing vent stacks, by Oatey Co., Cleveland, Ohio).*

17 **Hole Penetration:** *Using a utility knife, cut through the shingles to allow the roof flange to slide underneath. Pry the shingles up with a pry bar.*

18 **Roof Flange:** *Slide the 2-inch No-Calk Roof Flange, with neoprene gasket, up under the shingles, with the top edge at least 3 inches under the upper shingle. Seal the exposed edges with silicone. Slide insulation (1-inch wall, 3-inch outside diameter) up through the flange from below, and caulk with silicone where the insulation meets the gasket.*

19 **Piping:** *Slide the feed and return pipes down through the insulation, with tape across the bottom of the pipes to prevent clogging by debris. Run an electrician's snake through the insulation (do not touch the pipe) and pull the sensor wire up through the insulation.*

20 **Pipe Insulation:** *Connect the collectors to the feed and return headers with hoses, placing silicone in the joints prior to attaching. (If soldering, follow manufacturer's specifications. When 95/5 solder is specified, make sure it is Tin/Antimony, not Tin/Lead.) Attach the sensor wires. Prior to charging the system, tighten the hose clamps securely (at least three times at 4 hour intervals), insulate the headers and hoses, and paint or attach protective jackets to the insulation.*

ROOF LOADING CRITERIA

According to the Massachusetts State Building Code, the following criteria must be met to install solar collectors on roofs:

1. PITCH (tilt) of collectors CANNOT EXCEED 60°.
2. LENGTH of collector CANNOT EXCEED 9 feet
3. LOAD of collector CANNOT EXCEED 7 lbs/ft^2.
   Determine LOAD using this formula: $\frac{\text{weight}}{\text{length} \times \text{width}}$
   (this data is available on manufacturer's specs)
4. RAFTERS MUST BE ADEQUATE to support the load.
   Determine this in the following manner:
   1. Measure the distance from the underside of the collector to the roof. Note whether it is greater than or less than 3 feet.
   2. Measure the rafter size (round all measurements — 1½" x 9½" = 2 x 10.
   3. Determine wood type: Older houses normally have either fir or yellow pine rafters. Along with commonly available hemfir, they support 1200 psi. Many new homes are built with spruce which supports 800 psi. The wood type is often printed on the lumber itself.
   4. Determine roof construction: Light Roof Construction (LRC) consists of asphalt shingles over sheathing. It is the most common roofing. Heavy Roof Construction (HRC) includes slate or tile roofs and flat roofs with finished ceilings.
   5. Measure Span: Roof span, measured in feet and inches, is either
      1) the distance from bearing point to the roof ridge, or
      2) the distance from bearing point to bearing point depending upon construction.

Upon calculating this data, use the table on page 130 to determine the allowable rafter span:

If the roof span does not meet code, the roof **must** be reinforced. Reinforcement **must** be designed by licensed engineers or architects.

MAXIMUM ALLOWABLE SPAN

Member	800 psi Spruce		120 psi Hemfir		800 psi Spruce		1200 psi Hemfir	
	LRC	HRC	LRC	HRC	LRC	HRC	LRC	HRC
2 x 6								
12-OC	9′ 1	8′ 8	11′ 3	10′ 8	7′ 0	6′ 9	8′10	8′ 6
16-OC	7′11	7′ 5	9′ 9	9′ 3	6′ 0	5′10	7′ 6	7′ 3
24-OC	6′ 4	6′ 0	7′11	7′ 5	4′10	4′ 9	6′ 0	5′10
2 x 8								
12-OC	12′ 2	11′ 7	15′ 1	14′ 4	9′ 7	9′ 3	12′ 0	11′ 7
16-OC	10′ 6	10′ 0	13′ 0	12′ 4	8′ 2	8′11	10′ 3	9′11
24-OC	8′ 6	8′ 1	10′ 6	10′ 0	6′ 5	6′ 3	8′ 2	7′11
2 x 10								
12-OC	15′ 9	14′11	19′ 6	18′ 5	12′ 7	12′ 1	15′ 9	15′ 2
16-OC	13′ 6	12′10	16′ 9	15′10	10′ 9	10′ 4	13′ 5	12′11
24-OC	10′11	10′ 5	13′ 6	12′10	8′ 6	8′ 3	10′ 8	10′ 4
2 x 12								
12-OC	19′ 4	18′ 4	23′11	22′ 7	15′ 8	15′ 0	19′ 7	18′10
16-OC	16′ 8	15′ 9	20′ 6	19′ 5	13′ 4	12′10	16′ 9	16′ 1
24-OC	13′ 5	12′ 9	16′ 7	15′ 9	10′ 8	10′ 3	13′ 4	12′10

Transfer Fluids and Plumbing

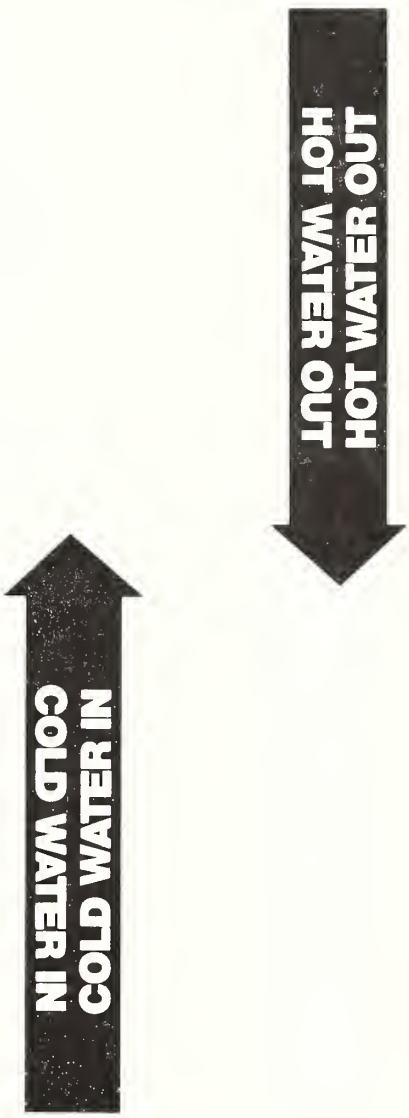
Each heat transfer fluid has differing properties, such as viscosity, specific heat, freezing, boiling, and flash points that will determine the size and design of many components.

CORROSION

The combination of dissimilar metals and any heat transfer fluid that conducts electricity will lead to galvanic corrosion. It can be avoided by:

1. Using a nonconductive heat transfer fluid, such as a silicone or hydrocarbon oil.
2. Using one metal throughout the whole system. If the metal is copper and the transfer fluid is water, there is no need to add corrosion inhibitors.
3. Using an air-to-water system.

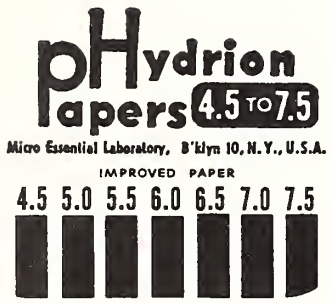
Most commercially available transfer fluids are sold with inhibitors already added, but some require the installer to add inhibitors. Water/glycol antifreeze mixtures require an added inhibitor because glycol products become acidic. Aluminum in the system will also require an inhibitor. Follow the manufacturer's directions carefully. Most of the common inhibitors carried in solution are sacrificial (the inhibitor is attacked, rather than the plumbing), and therefore require the installer or the owner to follow a regular maintenance schedule to check the transfer fluid. Be sure to flush the system completely (prior to filling) to remove solder flux, metal filings, etc. Direct connections between dissimilar metals must be avoided. Using insulating washers (plastic, rubber) or silicone hoses between dissimilar metals will reduce galvanic reactions at that point.



In solar collector systems, as in any system involving circulating liquids, it is not sufficient to use a dielectric fitting to

separate dissimilar metals from direct contact. Copper ions can be carried by the fluid and deposited on another metal, causing pitting. Although complex systems of corrosion protection are available for mixed-metal systems, the best solution is not to mix metals.

TYPES OF TRANSFER FLUIDS



Water

Water combined with dissimilar metals can cause galvanic corrosion. You need to know the pH and mineral hardness of local water before installing a system. Acid rain can also present severe problems. If local water conditions are extreme, chemical additives or electro-magnetic devices should be considered to protect the solar DHW system. The pH should be checked when the system is filled and at regular intervals to be certain that the water remains neutral and the pH is 7.0. The pH of water is normally 5.6 to 6.0. A qualified water treatment engineer can prescribe a treatment to make problem water safer for plumbing materials.

Whatever the local water conditions, distilled or deionized water is recommended for drainback systems with a heat exchanger. Draindown systems are particularly susceptible to variations in the acidity of local water supplies because they fill on demand. In a closed loop system, a non-acidic flux should be used to prevent chloride build-up which can cause pitting. Systems with water as a heat transfer fluid must use either all bronze or stainless steel pumps.

Water/Glycol Antifreeze Solutions

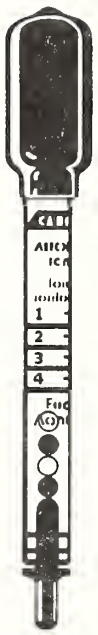
Care must be taken that the proper glycol mixture and heat exchanger have been specified. Ethylene glycol/water mixtures are TOXIC. According to the HUD Minimum Property Standards, a full double-walled heat exchanger must be used. Double-wall heat exchangers are more expensive and less efficient than single-walled.

Food-grade propylene glycol U.S.P./water mixtures — when certified nontoxic — can be used with a single-walled heat exchanger if no toxic dyes or inhibitors have been added to the mixture. Inhibitors which are Generally Recommended As Safe (GRAS) by the FDA, such as dipotassium hydrogen phosphate, should be added to U.S.P. propylene glycol to maintain the proper pH. Many manufacturers already do this.

Water/glycol solutions should be at least 20% glycol. The margin of freeze protection should be 10°F below the historic low of the region. A 50/50 solution is good down to -32°F, and maximum freeze protection is achieved with a 40/60 water/-glycol mixture.

Water/Glycol Installation, Safety, and Maintenance

Do not use glycol solutions with zinc galvanized plumbing because the required corrosion inhibitors react with zinc. Glycols may damage certain materials such as the butyl rubber membranes in certain types of expansion tanks. (Solar-type expansion tanks with EPDM bladders are available.) If water / glycol mixtures are exposed to repeated or prolonged stagnation temperatures, acids will form. If these conditions occur, the pH inhibitor strength and solution concentration of the water / glycol must be checked, and the solution should be replaced if necessary. Yearly fluid checks should be performed.



The Northeast Solar Energy Center and the National Association of Solar Contractors carried out a site evaluation program in 1980-81. (See Reprint.) In that study a positive correlation was found between controllers with high temperature limits (some were set as low as 140°F) and slightly acidic glycol mixtures. Systems using glycol based fluids must be designed to prevent stagnation. With properly installed and efficiently operating systems, glycol/water fluids have proven to be dependable heat transfer mediums.

Glycol solutions will leak through joints where water would not. Good seals and Teflon tape should be used. Glycol, if not already dyed, should be dyed with nontoxic food-coloring dye to help identify leaks. In case of leaks, additional water from the city water supply should not be added automatically as this will reduce the freeze protection. Depending on local codes, water / glycol solution should be drained into dry wells or waste drains (sanitary sewers, not storm sewers).

Paraffinic and Mineral Oils

Paraffinic or mineral oils are petroleum-based heat transfer fluids. Their useful temperature range is greater than that of water, and they are nonconducting. These oils have a higher viscosity than water and may require a larger pump. Because they will break down into tarry materials under prolonged exposure to heat, periodic replacement is necessary. Paraffinic oils are considered TOXIC and require a double-walled heat exchanger.

Aromatic Oils

Aromatic oils have lower viscosities than paraffins. This allows smaller pumps to be used. Aromatic oils have lower flash points which make them less safe to use in residential systems. They will dissolve roofing tar and most elastomer seals. Vitron seals should be used in all pumps and expansion tanks.

Silicone

Silicone heat transfer fluids are inert and will not cause galvanic corrosion. They will not degrade at high temperatures

and they have a very long operating life. Their disadvantages include high initial cost (approximately three-and-one-half times that of glycol), high operational cost, and systems that use silicone are prone to small leaks. Silicone has a high viscosity and low specific heat compared to water or water/glycol mixtures. Therefore, larger pumps and a flow rate two-and-one-half times that of water based systems should be used to get adequate heat removal from the collectors.

Silicone fluids will leak more rapidly through piping flaws than water. System piping layouts should be designed to reduce threaded connections and soldered joints. Avoid using silicone tubing or silicone sealants in the system. Use seal-less pumps with magnetic drives. EPDM or Vitron seals are preferred. Use a non-acidic flux when soldering to prevent contamination of the silicone. Care should be taken in selecting components which can be put together without leaking. Only manufacturer-recommended pipe dope should be used at all threaded joints.

Air

Solar domestic hot water systems which use air panels are not widely accepted. An advantage of air is that it can not freeze or boil and is non-corrosive. Because, it is very light and has low specific heat, operational costs tend to be high. Solar air space heating systems can heat domestic water. This is accomplished with the use of an air-to-water heat exchanger. If this is done, a backdraft damper should be installed in the air ducts to prevent reverse thermosiphoning which can freeze the air-to-water heat exchanger.

CHARACTERISTICS OF TYPICAL HEAT TRANSFER LIQUIDS

	Water	50% Ethylene Glycol/Water	60% Propylene Glycol/Water	Silicone Fluid	Aromatics	Paraffinic Oil
Freezing Point, °F (°C)	32(0)	-33(-36)	-48(-55)	-58(-50)	-100 to -25 (-73 to -32)	—
Boiling Point, (@ atm. pres.)	212(100)	230(110)	—	none	300-400 (149-204)	700(371)
Fluid Stability	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	good	good	good
Flash point	none	none	none	600(315)	145-300 (63-149)	455(235)
Specific heat (@73°F) (Btu/lb°F)	1.0	0.80	0.808	.34-.48	.36-.42	.46
Viscosity Centipoise	.5-.9	1.2-4.4	1.4-7.0	10-20	.6-.8	12-30
Toxicity	Depends on inhibitor used	high	Food-grade (GRAS) inhibitors available	low	moderate	—

*(**note:** Because viscosity is sensitive to temperature, values are given for a temperature range of approximately 80°F.)*

RECOMMENDED TYPES OF PLUMBING

The most favored plumbing for solar DHW systems is sweat-soldered M-type copper tubing if it is permitted by local building codes. Copper tubing joints in and near the collector array should be soldered with 95-5 tin-antimony solder to avoid joint failure at stagnation temperature. While 95-5 could be used throughout the rest of the system and should be used in a silicone system, 50/50 tin-lead solder can be substituted in those parts of the system that will not be subjected to the extremes of stagnation temperatures. Remember that silicones and glycols demand well-soldered joints.

Although soldered joints are preferred, threaded joints may be made with a good quality joint compound and/or Teflon pipe dope with Teflon (part No. 259), Crane Je-30 pipe thread sealer with Teflon, Rector Seal No. 5, and Dow Corning 730 Fluorosilicone rubber sealant, and their equivalents.

If concentrating or evacuated-tube collectors are to be used, silver solder or brazing alloys are required throughout the system because of high temperatures. Some building codes demand the use of silver solder, silver-bearing filler metals, or other brazing alloys for all concealed pipe runs in ditches and walls. Check your local codes before proceeding.

Plastic Pipe

Do not use PVC for hot water applications. CPVC will sag at about 160°F if it is not adequately supported. Sags in piping will prevent complete draining of drain-down or drain-back systems, and will make air elimination on closed loop systems more difficult. Polybutylene has higher temperature resistance than CPVC, but will begin to sag at about 200°F. Unpressurized systems offer a more favorable environment for plastic piping than closed loop systems. In evaluating whether plastic piping will reduce installed cost, one must consider the extra time involved in adequately supporting the piping.

Galvanized Threaded Pipe

Conventional galvanized threaded pipe may be used if already installed in the existing DHW system. All threaded joints should be thoroughly pipe doped.

Silicone Coupling Hoses

Silicone coupling hoses are sometimes specified by manufacturers for connecting collectors. Silicone hoses should be clamped with special, shielded clamps. Hoses offer heat free coupling and control of expansion but have a much higher failure rate than joining collectors with soldered couplings.

Pipe Runs

Choosing the path for the pipe run is often the most difficult part of installing a solar domestic hot water system. Ideally, the run

should be straight from the tank to the collectors, and nearly all of it should be inside the heated spaces of the building, out of sight in wall partitions or closets. In any solar loop, one leg is shorter than the other, and this shorter leg should be the return from the collector. Pipe runs should be well-insulated so it is possible to install tanks that are over 150 feet away from the collector array and still have adequate performance. In new construction, contractors can often arrange for a 2″ by 6″ stud wall partition to be built in place of a standard 2″ by 4″ wall. The 2″ by 6″ wall is wide enough to run ¾″ to 1½″ pipe with 1″ wall pipe insulation.

CHART FOR HANGING AND ANCHORING PIPE

PIPE	VERTICAL	HORIZONTAL
Copper tubing	one story or 10-foot intervals	8-foot intervals for drawn tube 6-foot intervals for annealed tube.
Threaded Pipe	every other story	12-foot intervals
Rigid Plastic	half story intervals	1- to 2-foot intervals

EXPANSION

All pipe should be supported so that it can expand and contract with temperature changes. A 100′ length of copper will expand and contract approximately 1″ within a 100°F temperature swing. Depending on the exact type, plastic pipe will contract or expand 2″ - 3″. Piping can be installed with right angle sections which will accommodate normal expansion and contraction. For long straight sections, "U" expansion sections can be designed in. If space is tight, corrugated or slip-type expansion joints can be used. Silicone hoses can also be used as expansion joints.

UNDERGROUND PIPING

Underground piping work is the most expensive type of piping and should be avoided if possible. When necessary, it should be simplified to avoid joints below grade. Use coils of type "K" copper, a flexible type pipe insulation, and an outer waterproof pipe (non-perforated 4″ corrugated drain piping works). For large scale applications, there are suppliers of underground piping systems. Piping should be insulated to at least R-4 and buried below the frost line. To keep insulation dry, the pipe should be wrapped in roofing paper and sealed with hot pitch. Buried pipe runs should contain as few joints as possible. Some codes will not allow any buried joints.

Plumbing that runs through or under a foundation should pass through an iron pipe sleeve two sizes larger than the insulated pipe, and the gap should be filled with sealant or other approved material. Ask your local plumbing inspector for suggested equivalent protection.

Make sure that the pipe does not rest on any rocks in the trench, and do not support it on blocks. Avoid high spots that may trap air. The pipe should rest on firmly packed earth or — if the bottom of the trench is rocky or uneven — on a six-inch level layer of tamped sand. If soft soil of poor bearing quality is found at the bottom of the trench, deepen the trench by two pipe diameters and backfill with a layer of fine gravel or crushed stone two pipe diameters deep.

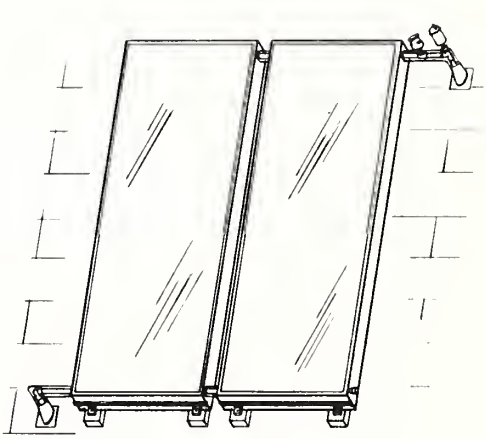
While backfilling the trench, be sure that rocks, broken concrete, or other construction litter does not damage the wrapped and insulated pipe. Six inches of earth should be dumped into the trench, carefully tamped around the pipe to assure proper support and alignment, and then covered with a layer of treated boards to prevent damage to the pipe from future digging. The remaining depth should be filled and tamped at 6″ to 12″ intervals to prevent unsightly settling of the lawn.

SIZING PIPING

Piping should be sized to balance the cost of piping against adequate heat removal from the collector, effective heat transfer through heat exchangers, and pumping costs. Additionally, flow rates should be kept below 4 feet per second to reduce corrosion in copper. Most residential SDHW systems use ¾″-piping. Systems which have collector areas larger than 125 square feet should consider using 1″ piping. Standard pipe friction tables will help you determine the amount of resistance for the type and length of the plumbing used. Remember that pipe friction will vary with heat transfer fluid, flow rate, and plumbing materials. (See Chapter on Pumps.)

INSTALLATION TIPS

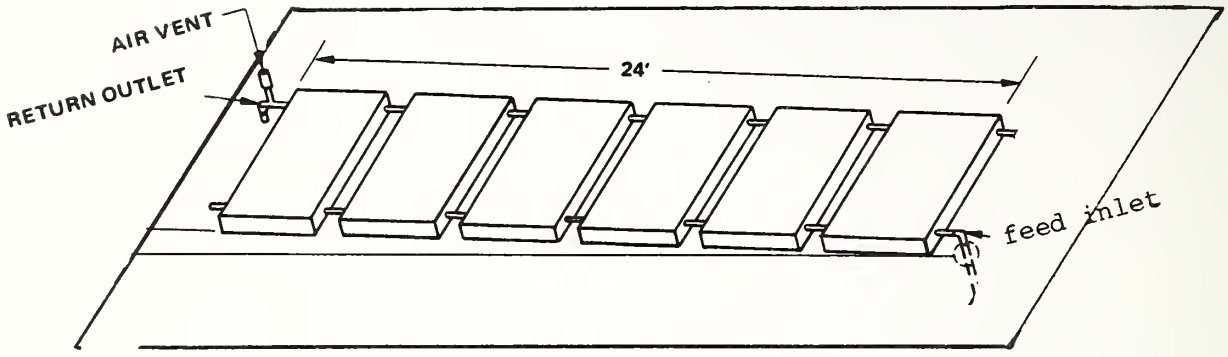
Keep insides of all tubes or pipes clean and ream out the ends of all pipes and tubing. Use sandpaper or emery cloth on the outside surface of the ends of copper tubing and on the inside surface of all copper fittings before soldering. Surfaces must have a bright finish. Bend copper tubing (providing it is annealed or "soft" tubing) rather than use elbows or other fittings. This will reduce friction losses. Avoid sharp bends and use bending tools whenever possible. Eccentric reducers may be used to join horizontal pipe of different sizes and to avoid trapping air.



REVERSE RETURN HOOKUPS

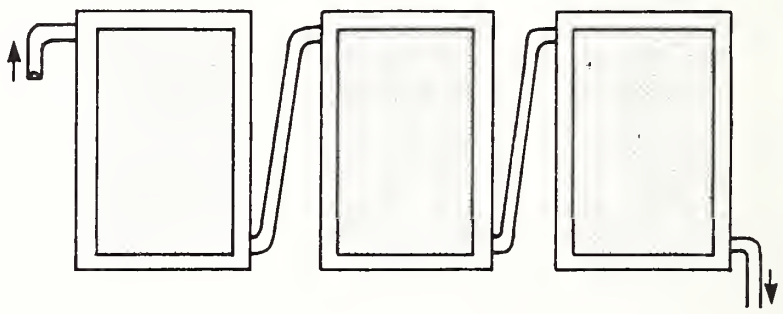
Collectors should be piped so that fluid will flow evenly through all of the collector's riser tubes. This is to ensure equal heat

removal from all areas of the collector array. Sets of collectors should be piped with the feed pipe from the tank connecting to either one of the lower corners of the manifold. The return to the tank should be piped from the diagonally opposite upper corner of the array. This method is called REVERSE RETURN.



SERIES HOOKUPS

When connected in a series, collectors obtain higher temperatures thereby reducing collector efficiency. Series hookups are not recommended for solar DHW systems unless specified by the designer.



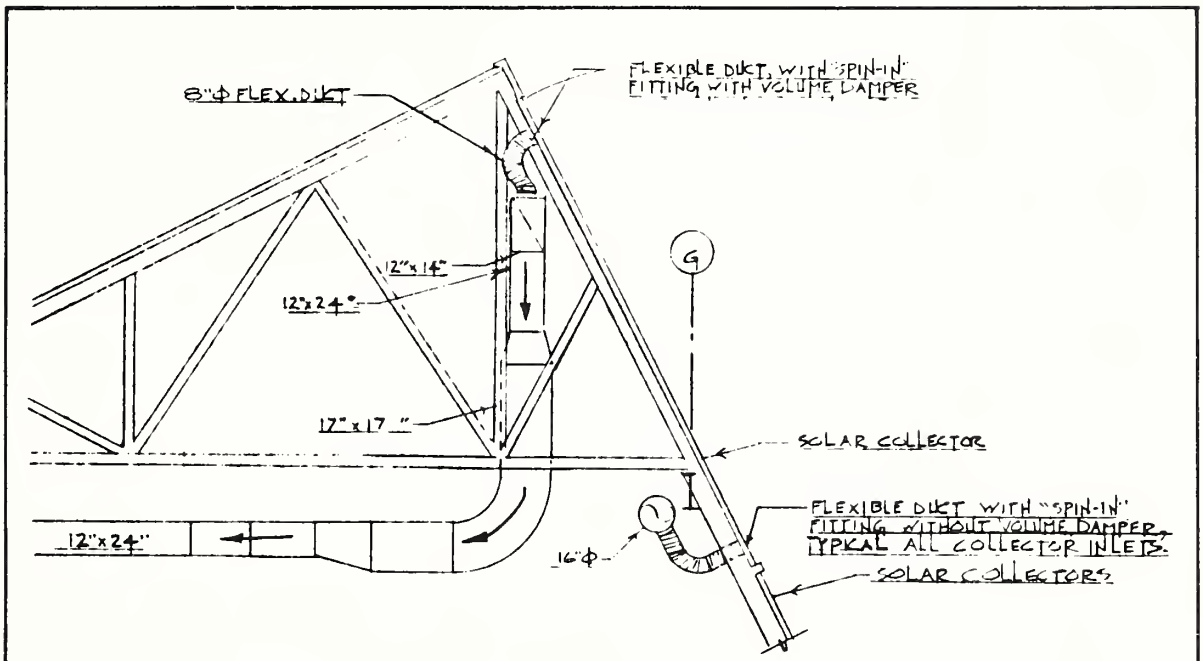
DUCTWORK FOR AIR DHW SYSTEMS

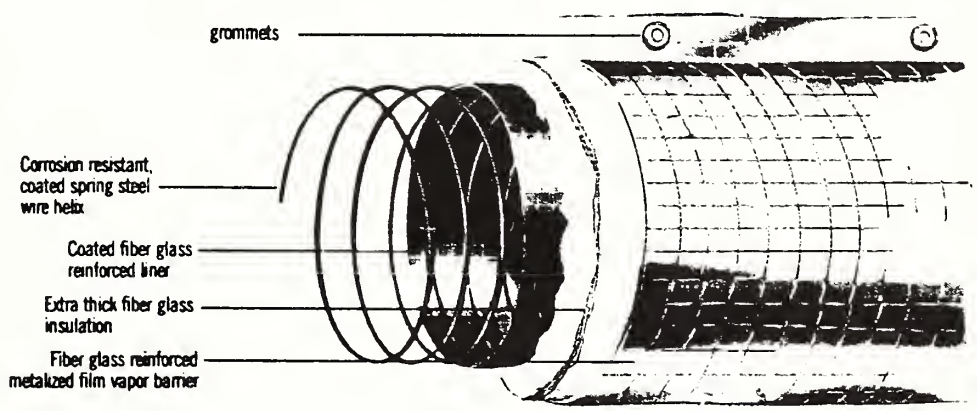
Ductwork should not leak more than 5% at design flow rate. Use conventional methods for sizing and employing the minimum allowable gauge to reduce the amount of heat retained within the ductwork.

Because of low-leakage requirements, only metal or properly installed and sealed fiberglass ducts should be used. Take special care on corners when joining ductwork to seal edges. A Pittsburgh lock seam is recommended, and added protection may be achieved by applying a product such as 3M's EC-800® in the seam before joining and caulking all joints. Joints should be fastened with sheet metal screws or rivets so that the ductwork maintains its integrity through repeated expansions and con-

tractions. Prefabricated swivel ductwork has a tendency to leak more than custom made ducts. Avoid such items whenever possible.

Duct hangers should be spaced according to conventional standards. They should wrap around the insulation and not penetrate it. In DHW solar systems, spacing of hangers will typically be 10 feet on center.




grommets
Corrosion resistant, coated spring steel wire helix
Coated fiber glass reinforced liner
Extra thick fiber glass insulation
Fiber glass reinforced metalized film vapor barrier

CHAPTER SIX

Pipe Insulation

The ability of pipe insulation to deliver Btu's is just as critical to the performance of the whole solar system as the quality of the collectors, tanks and controller. Heatloss from pipes should be reduced so that the piping system yields a comparable overall return to that of the entire system. There are eight general considerations to keep in mind when selecting pipe insulation for a job. They are:

R-Value
Cost
Ease of Installation
UV Resistance/Treatment
Sizes Available
Temperature Range
Flame Resistance
Installed Appearance

Exterior Pipe Insulation

Exterior pipe insulation and jackets must be able to withstand prolonged exposure to sunlight and remain waterproof. UV resistance is critical in all exterior piping. In addition it must be capable of withstanding the highest loop temperatures because it is connected to the collector outlet. Since there is a large temperature differential outside, R-7 is needed. It is helpful if the installer gets to know the insulation supplier. A supplier can give specific advice on how the products are applied. In order for an installed system to act as a sales tool, extreme care must be

taken when insulating pipework. Bleached duct tape blowing in the wind or cracked painted insulation will not lead to future sales.

Interior Pipe Insulation

A great variety of products and techniques are available to the installer. Isocyanurate and fiberglass snap-on pipe insulation are all available and can be installed in single thicknesses (1″) to meet the HUD R-4 minimum standard. Elastomer and polyethylene can also be used, however, two layers are necessary to meet the R-4 specifications.

Site-Evaluation Study

The following remarks are based on the experience of the Site-Evaluation Study conducted by the Northeast Solar Energy Center in 1980. (See Reprint) A team of solar contractors evaluated installed SDHW systems in New England. The team quickly agreed that the quality of the pipe insulation and the care given to installing it by the contractor were two of the most revealing indicators of overall quality in the system design.

In their examinations, the evaluators found numerous systems with pipe runs that had no insulation or loosely fitting insulation. In many cases an elastomer type pipe insulation was used. It was often installed by slitting it to wrap around the pipes. However, over time the elastomer pipe insulation embrittled and shrank, leaving the pipes exposed to the air. On inspection several years later, snap-on fiberglass or isocyanurate insulation had remained generally in the same condition as when it was applied.

TYPES OF PIPE INSULATION

Selection Criteria

There are four insulation materials used on solar piping. They are Elastomer, Polyethylene, Fiberglass and Isocyanurate. The two primary selection criteria are:

Thermal Resistance — "R-Value"
Ultraviolet Resistance — "UV Stable"

Isocyanurate

Isocyanurate is a polyisocyanurate foam. It is fabricated into round lengths of insulation and often jacketed at the fabricators for distribution. It yields a higher service temperature and slightly greater thermal resistance than urethane. It is supplied in snap-on lengths, pre-insulated pipe and in two piece fittings for elbows, tees and angles. Although urethane is made from a similar material and costs less than isocyanurate, the higher service temperature of isocyanurates makes them preferable.

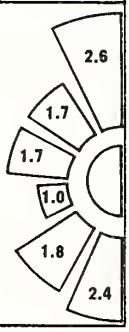
Note: *Urethane and isocyanurate give off toxic fumes when burned. Certain states have preventative codes restricting the use of isocyanurate indoors. Do not use near a source of combustion.*

Fiberglass
High density (3 lb.), compressed fiberglass pipe insulation is made with high temperature binders. It is available in snap-on lengths and fittings. Fiberglass pipe insulation has several advantages. It has a high service temperature, high resistance to fire and is priced low.

Polyethylene
Polyethylene is available in flexible, pre-split lengths or with a "zip-lock" fastening. Installation is easy when this flexible tubing is used, especially in hard to reach areas where snap-on insulation cannot be used. It has a low cost and somewhat higher R-Value than elastomer.

Elastomer
Elastomer insulation is a closed cell material that is supplied in lengths of flexible tubing. It has been widely used in the plumbing HVAC trades. While it behaved acceptably in those trades, it has had a very high rate of failure in the solar trade. Much of the failure comes from poor installation practices. If elastomer is cut, special glues must be used to reseal the cut. Since solar loop piping tends to be more complex than standard refrigeration loops, installers have more frequently installed elastomer pipe insulation after the systems are completed and checked for leaks. Since gluing seams requires more time and care than using snap-on insulation, often installers neglect to glue the elastomer which only increases the failure rate. Elastomer and polyethylene are not recommended if the temperature in the piping loop exceeds 200°F. Elastomer tends to shrink and embrittle (lose flexibility) if exposed to higher temperatures.

	K Factor @ 75° F.	Weight Equiv-alent	Equivalent Thickness
Cellular Glass (9.0 pcf)	0.40	11.7	
Polystyrene Foam (2.0 pcf)	0.26	1.7	
Glass Fiber (3.6 pcf)	0.25	3.1	
CPR Urethane Foam (2.0 pcf)	0.14	1.0	
Cork (6.5 pcf)	0.31	5.8	
Asbestos Fiber (16.0 pcf)	0.36	19.2	



PIPE INSULATION COMPARISONS

	Fiberglass	Isocyanurate	Elastomer	Polyethylene
R-Value/inch at 75°F	4.2	7.0	3.9	4.2
Cost/Linear foot (⅞" x 1" wall)	$ .75	$1.05	$ .76	$ .60
Unit cost/R-Value	$ .18	$ .15	$ .19	$ .14
Pipe Sizes	⅝" - 36"	⅝" - 2⅛"	⅜" - 4⅛"	½" - 5"
Service Temperature Range	-60° to +650°F	-50° to +300°F	-40° to +220°F	-90° to +212°F
Flame Spread	25	30-75	25	25
R-4 Dia. Requires 1" (Interior)	1"	⅝"	1⅛"	1"
R-7 Dia. Requires 1¾" (Exterior)	1¾"	1"	2"	1¾"

Note: *Prices are based on costs to installers.*

INSULATION COVERINGS

There are four types of insulation coverings available: ASJ, PVC, metal jackets and waterproof mastic.

ASJ — All Service Jacket

ASJ is a paper jacket which is reinforced with fiberglass threads. It may come with a reflective inside and white exterior finish. All Service Jacket is available on urethane, isocyanurate, phenolic foam and fiberglass insulation. It is for interior use only. Some manufacturers supply pre-glued laps which are generally more expensive. If staples are used to close the jacket, the outward clinching type is recommended. Tacks are also available.

PVC — Polyvinylchloride

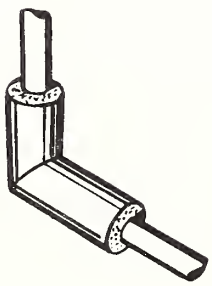
UV protected polyvinylchloride (PVC) is an excellent low maintenance pipe insulation covering designed for outdoor use. It is an opaque rigid vinyl with high toughness that is noted for its retention of impact strength and color in extreme weather conditions. It is available on most types of insulation and for elbows and tees. Adhesive is needed to seal the PVC. Field experience has shown that regular duct tape, electrical tape, and PVC tapes do not hold up over time. Mechanical fasteners such as stainless steel threaded tacks and stainless steel outward clinching staples may also be used. Some PVC jackets have a strip of tape inside them to hold the jacket in place while applying sealant.

Metal Jackets

Aluminum or stainless steel jackets are strong and durable and are not affected by the sun. They are generally an industrial type product. Some installers like their clean appearance and long life span. Joints are fastened with staples or tacks. Seams are sealed with clear silicone sealant.

Mastic and Paints

Mastic and paints can be used on unjacketed isocyanurate and elastomer insulation. Mastic used on elastomers has not been successful due to shrinkage. Manufacturers recommend recoating the insulation every two to three years. Some mastics are available specifically for isocyanurates with the manufacturer claims offering at least five years of service. The coating is a thick latex which has a rough appearance when applied and may look dirty quickly. It is less expensive and less durable than PVC jackets.



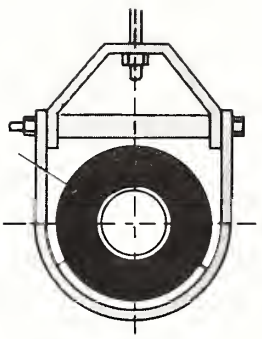
FINAL NOTES

Do not insulate the following components:

- ***Tops of air vents***

- ***Pump motor housing***
- ***Tempering valves***
- ***Vacuum breakers***
- ***Temperature and pressure relief valves***

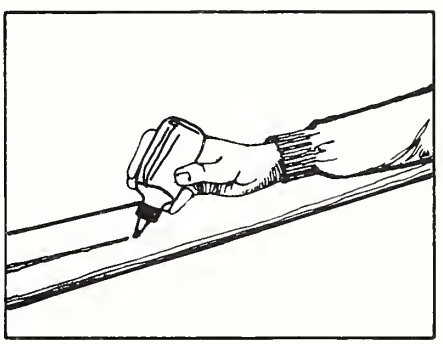
Sensor Wires
Do not run sensor wires from the collector or storage tank against the solar loop piping. These wires can be run inside the insulation jacket, away from all fastenings. This is particularly important on exterior pipe runs.



Pipe Supports
Pipes should be supported as standard practice dictates. Care should be taken to use hangers or pipe strapping which does not damage the covering or the insulation. Standard hangers which support the piping directly are not recommended because they create a thermal short circuit.

ECONOMICS OF INSULATION

To compare the economics of the different materials, it is necessary to compute the heat loss of the solar loop and determine its value in dollars. The pertinent heat transfer equation is:

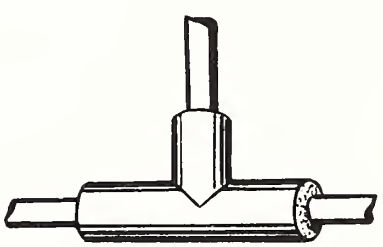


$$Q_l = \frac{2\pi(T_f - T_a)}{\frac{1}{r_f h_f} + R_c(\ln r_c/r_f) + R_i(\ln r_i/r_c) + \frac{1}{r_i h_a}}$$

Where: Q_l = heat loss per foot of insulation in Btu/hr
T_f = Temperature of the fluid in the loop
T_a = Temperature of the air
r_f = inside radius of the pipe
r_c = radius from center of pipe to outside of copper
r_i = radius from center of pipe to outside of insulation
h_f = heat transfer coefficient of the fluid
h_a = heat transfer coefficient of the air
R_c = Thermal resistance of the copper
R_i = Thermal resistance of the insulation
ln = Natural log base e

Fortunately, many of the values are so small that they can be neglected in this analysis. The following is a workable version:

$$Q_l = \frac{2\pi(T_f - T_a)}{R_i(\ln r_i/r_c) + \frac{1}{r_i h_a}}$$



Elastomer

To use the equation for elastomer as an example, let's assume that we are thinking of the ¾-inch wall size and that the temperature difference between the solar fluid and the outside air is 50°F.

assumptions: $T_f - T_a = 50$

$$*R_i = 46.2 \frac{\text{hr ft °F}}{\text{Btu}}$$

$$r_c = .4375 \text{ in}$$

$$r_i = (.75 \text{ in} + .4375 \text{ in}) = 1.1875 \text{ in } (.0989 \text{ ft})$$

$$h_a = .68 \frac{\text{Btu}}{\text{hr ft °F}}$$

$$Q_l = \frac{2\pi(50°F)}{\frac{46.2 \text{ hr ft °F}}{\text{Btu}} \ln \frac{1.1875 \text{ in}}{.4375 \text{ in}} + \frac{1}{.0989 \frac{.68 \text{ Btu}}{\text{hr ft °F}}}}$$

$$Q_l = \frac{2\pi(50°F)}{\frac{46.2 \text{ hr ft °F}}{\text{Btu}} + \frac{14.9 \text{ hr ft °F}}{\text{Btu}}}$$

$$Q_l = \frac{5.15077 \text{ Btu}}{\text{hr ft}}$$

*R_i must be expressed in feet

Isocyanurate

To use the equation for 1-inch isocyanurate, by comparison, the following variables change:

$$*R_i = 96 \frac{\text{hr ft °F}}{\text{Btu}}$$

$$r_i = (1 \text{ in} + .4375 \text{ in}) = 1.4375 \text{ in } (.1198 \text{ ft})$$

$$Q_l = \frac{2\pi(50°F)}{\frac{96 \text{ hr ft °F}}{\text{Btu}} \ln \frac{1.4375 \text{ in}}{.4375 \text{ in}} + \frac{1}{.1198 \frac{.68 \text{ Btu}}{\text{hr ft °F}}}}$$

$$Q_l = \frac{2\pi(50°F)}{\frac{114.2 \text{ hr ft °F}}{\text{Btu}} + \frac{12.3 \text{ hr ft °F}}{\text{Btu}}}$$

$$Q_l = \frac{2.48 \text{ Btu}}{\text{hr ft}}$$

*R_i must be expressed in feet

The numbers confirm that isocyanurate is more than twice as effective an insulating material as elastomer. To analyze the materials in terms of dollars and cents, consider a solar loop of 120 total feet (to and from collectors) which operates six hours per day, 220 days per year:

For elastomer

$$\frac{5.15\ \text{Btu}}{\text{hr ft}} \times 120\ \text{ft} \times \frac{6\ \text{hr}}{\text{day}} \times \frac{220\ \text{days}}{\text{year}} = \frac{815{,}760}{\text{Btu/yr}}$$

For Isocyanurate

$$\frac{2.48\ \text{Btu}}{\text{hr ft}} \times 120\ \text{ft} \times \frac{6\ \text{hr}}{\text{day}} \times \frac{220\ \text{days}}{\text{year}} = \frac{392{,}832}{\text{Btu/yr}}$$

The difference (savings with isocyanurate) = 422, 928 Btu/yr.

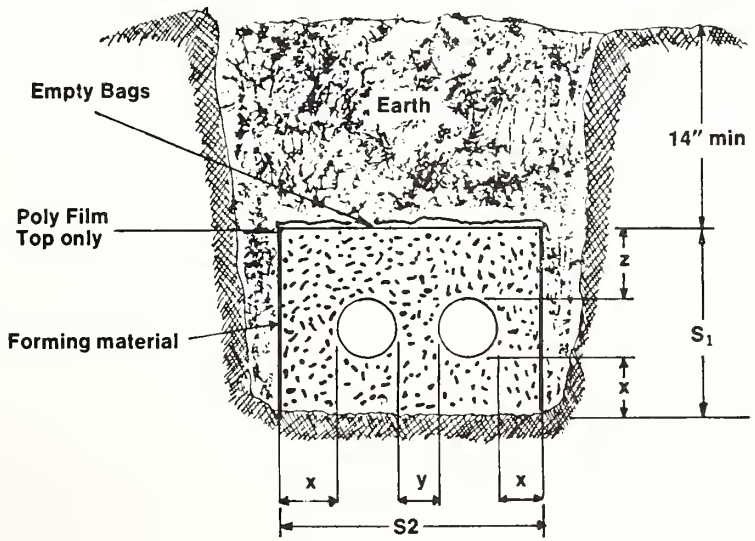
Let us now assume that the backup energy source is off-peak electricity, costing $.077 per kWh. The resulting savings with isocyanurate are:

$$\frac{422,928\ \text{Btu/year}}{3{,}412\ \text{Btu/kWh}} = 124\ \text{kWh/year}$$

$$124\ \text{kWh/year} \times \$.077/\text{kWh} = \$9.55$$

According to our early tables, 120 feet of isocyanurate would cost the contractor $126.00, or $34.80 more than elastomer. If the contractor marks up materials 50%, the isocyanurate would cost the homeowner approximately $50.00 more. From that $50.00, however, the homeowner is able to deduct the 40% federal residential solar tax credit. The net added cost for isocyanurate, then, is $32.00. This $32.00 gives a savings of $9.55 per year. In other words, the return on investment for first rate solar loop insulation is 30 percent. Any state tax credits or increases in the cost of electricity make the investment look even better.

The especially nice feature of an investment in insulation is that the return comes tax-free, in the form of energy savings.



Pumps, Valves, Gauges and Expansion Tanks

PUMP SELECTION CRITERIA

The pump is the heart of the active solar DHW system. It is also one of the few parts of the system accounting for an energy loss rather than an energy gain, so it should be understood and respected. Most pumps used in SDHW systems are small, magnetically-coupled in-line centrifugal circulators. These pumps, commonly referred to as "circulators," have no troublesome rotating seals. Instead, the rotor of the electric motor and its bearings are placed entirely inside an extension of the circulator housing. The stator of the motor is outside of the pump housing and drives the rotor with a rotating magnetic field.

Magnetically coupled, centrifugal pumps can be expected to last the lifetime of the system. Centrifugal pumps offer the advantage of pumping only slightly above rated pressure if fluid flow stops due to some blockage in the loop, thus avoiding damage to the pump and the loop. Centrifugal pumps increase their flow rate with increased temperature, due to viscosity change, and thus improve heat transfer at higher temperatures. Finally, centrifugal pumps are compact, light and easy to service.

There are two major areas of concern in selecting pumps for solar systems:

- ***System Type and Required Pump Discharge Pressure at Design Flow Rate***
- ***Pump Compatibility with selected Heat Transfer Fluid***

The following pages discuss these concerns in a general way. At the end of the chapter, a summary presents simple techniques for sizing pumps and expansion tanks for various types of systems.

FLOW RATES, SYSTEM TYPE AND PRESSURE DROP

Flow Rate

Flow Rate is the amount of fluid moving past a given point over a period of time, and is usually expressed in Gallons per Minute (GPM). Sufficient quantities of heat transfer fluid must be passed through the collectors to efficiently remove heat from them for transfer to the storage tank. Therefore, a Design Flow Rate must be determined for the system, based on the number of collectors in the system and the manufacturer's recommendations for the collectors (and sometimes for the heat exchanger). Required flow rates tend to cover a fairly broad range, typically between .015 to .05 gal/min/ft^2 of collector absorber.

Since the various heat transfer fluids have different specific heats, flow rate requirements for a given collector will change with each fluid. Water, with a specific heat of 1.0, requires the lowest flow rates for effective heat removal — for example, about .50 gpm for a 4′ by 8′ collector. Silicone fluids, with a specific heat of .38 at 120°F, require almost three times that flow rate to remove an equal amount of heat (about 1.4 gpm). Water/glycol solutions have a specific heat of .82 and require a flow rate of 19% more than water, about .59 gpm (since water/glycol solutions pump easier than water, this is easy to achieve).

Pressure Drop

Pressure must always be applied to move a quantity of water through a system of piping. The amount of pressure required to move a given amount of water through a specific piping system at a set velocity or flow rate is expressed in terms of PRESSURE DROP or HEAD LOSS, and is measured in PSI (pounds per square inch) or FEET OF HEAD (1 psi = 2.21 feet of head). Water being pushed through a piping system will be under greater pressure at the inlet of the pipe than at the outlet of the pipe. If water pressure is measured at both ends, the pressure drop or head loss is simply the difference in pressure between the inlet and outlet. In any specific piping system, greater pressure is required to move fluid at a greater rate, so we say that pressure drop increases as flow rate increases.

Two sources of pressure drops may be present in SDHW systems — **FRICTIONAL LOSSES** and **STATIC HEAD LOSSES.**

Frictional Losses

Frictional losses are due to the resistance of piping and other system components to the flow of fluid, and as noted above are proportional to the velocity of the fluid. Tables are available from various sources which show the relationship between flow rate and pressure drop for copper pipe, absorber plates, heat exchangers and other components used in solar systems, and these are used to calculate the total of the System Pressure Drop

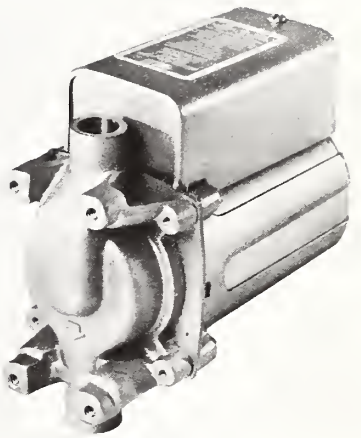
at the Design Flow Rate, given the number of absorbers, amount of pipe and so forth for a given system. The sum of the head losses for individual components equals the total head loss for the system. The ASHRAE Handbook of Fundamentals, Chapter 32, "Pipe Sizing," gives a method for calculating head loss caused by friction in pipes.

Static losses are imposed solely by the requirement to lift the fluid above its normal level to a given higher level, or head, and are not related to flow rates. Strictly speaking, static losses are equivalent to the work required to slowly lift the required quantity of water the required height. The static loss can be directly determined in feet of head by measuring the difference in height between the two fluid levels.

Different solar systems can have very different pressure drops depending on system type as well as size. The most dramatic differences are seen between the closed loop systems and the various open loop systems.

Pump Sizes in Closed Loop Systems

In closed loop systems only frictional losses need be considered. Because the fluid being pumped up to the collectors is counterbalanced by the fluid dropping down from them, no work is done in lifting the fluid. But work must be done to overcome the friction of the whole circuit of piping, absorbers and heat exchangers. Therefore the total frictional losses of the system must be calculated. Most closed loop SDHW systems use 1/25-or 1/20-horsepower circulators.



Pump Sizes in Open Loop Systems

In open loop systems water must be pumped up to the top of the collectors to establish system flow. The pump must be capable of overcoming frictional losses of the piping circuit once circulation is established, just as in a closed loop system. It must also be able to overcome the static loss and lift the water above the top of the collector. In most open loop SDHW systems the static head loss is much greater than the frictional losses of the system, and thus establishes the lifting ability of the required circulator. Circulators used in open loop systems therefore tend to be larger than those used in closed loop systems, usually 1/12- or 1/6-horsepower.

In an open loop drain back system, the storage tank is also the reservoir tank. The circulator must be able to lift the water up over the top of the collectors, so a circulator must be chosen which has a static head equal to or greater than the height of the top of the collectors above the reservoir tank.

After circulation is established through the system, the pump need only overcome the pipe friction losses. The pump which

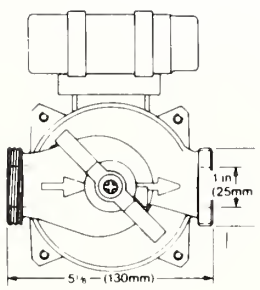
could overcome the static head of the system is now too powerful for the pipe friction losses alone. Several methods are used to deal with this problem.

Often, the flow rate is regulated by installing a throttling valve (ball valve) in the return pipe from the collector.

If two pumps are installed in series to achieve the static head requirement of the system, the pumps can be staged so that the two pumps turn on to fill the system loop, with one pump shutting off after a short time. The operating pump will only pump against the pipe friction losses, and not the vertical head. A two speed pump can also be set up to operate in the same manner.

Another system, the "siphon return" drainback, uses a reduced size downcomer pipe so that overall system friction losses are approximately the same as the head losses at start-up. A balancing valve is used to fine-tune the pressure drop through the system.

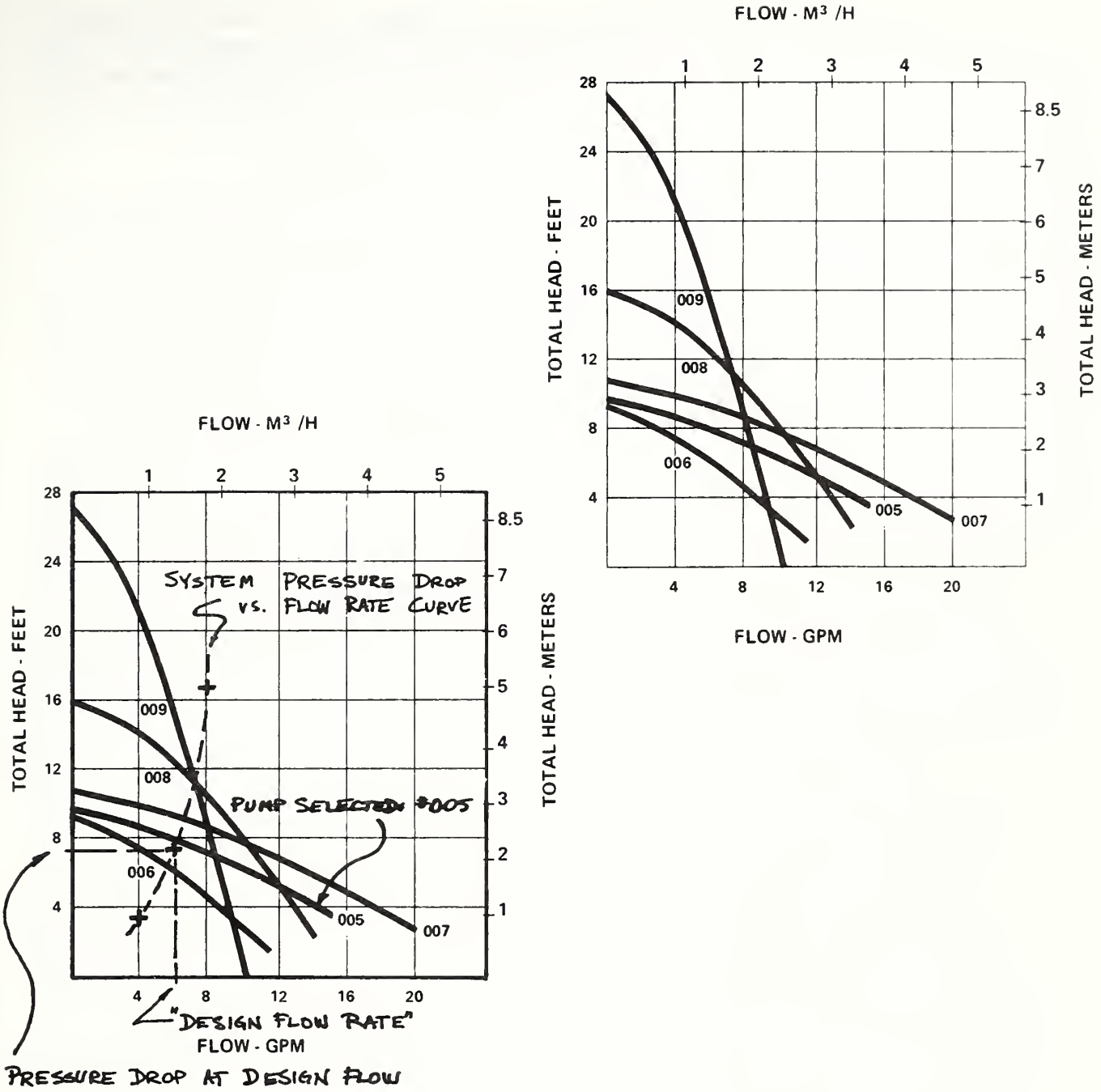
Yet another strategy is to locate a reservoir tank high up on the return line near the collectors, so that the non-pumped water level is held within a few feet of the collector tops. The reservoir tank can be anywhere in the return line as long as it is in a heated area. When the tank is installed within 12 feet of the top of the collector, a 1/20- to 1/25-horsepower pump, located well below the reservoir to maintain its prime, is usually sufficient to circulate the fluid.



Domestic water/draindown systems are pressurized by house water pressure, using spool type or solenoid valves. When the controller signals the valve to open, water fills the system, pushed by household water pressure. Once the system loop is filled with water, the pump need only circulate the water. A 1/35- to 1/20 horsepower stainless steel or bronze pump is generally adequate to overcome the pipe friction losses in these systems, and can be sized using methods that work for closed loop systems.

PUMP PERFORMANCE CURVES AND SPECIFYING PUMPS

Figure A shows a typical pump performance curve which shows pump discharge pressure, or head, over the available flow rate range for specific pumps. These curves can be obtained from pump manufacturers and distributors. To use the curves in selecting a pump, you must know the pressure drops of the system at various flow rates near the Design Flow Rate. In Figure B we show a complete plot of a system's head requirement at various flow rates, superimposed on a pump perfor-



mance curve. This system, when outfitted with this pump, will operate at the flow rate and pressure drop shown at the intersection of the two curves. Usually, only a small part of the system curve is plotted, near the target flow rate. The designer must select a circulator that will give a flow rate within five percent of the Design Flow Rate.

Net Positive Suction Head

In open-loop systems with larger pumps, Net Positive Suction Head (NPSH) may be a concern. NPSH requirements for specific pumps can be obtained from the manufacturer.

Net positive suction head is the absolute head at the pump inlet minus the vapor head of the liquid being pumped. If the NPSH does not exceed the pump's NPSH requirement, cavitation can occur and can destroy the pump in a short time.

PUMP COMPATIBILITY WITH HEAT TRANSFER FLUID

Corrosion is the breakdown of material at the molecular level. Factors which make circulators used in solar systems particularly susceptible to corrosion are acids, oxygen, high temperatures and electrolysis, and these often work together. For example, the turbulence created by the pump effectively increases the surface area available for acidic and oxidizing corrosion, thereby intensifying the chemical reactions.

Pump Materials Used in Closed Loop Systems

In closed loop systems, cast iron can be used in the circulator. Glycols, silicone, etc. do not promote rust. In closed loop drainback systems, cast-iron in the pump housing may rust slightly due to oxygen contained in the water, but this will not damage the pump. In anti-freeze systems, the pH of the fluid must be maintained between seven and nine. If the fluid becomes acidic, the pump will quickly deteriorate.

Galvanized pipes should not be used with glycol solutions due to the reaction of common corrosion inhibitors with zinc. Magnetic-drive or canned wet-rotor pumps should always be used with oil transfer fluids due to its extreme leakage potential. Polyethylene and polypropylene seals should not be used with petroleum based heat transfer fluids as they will gradually degrade from exposure.

Pump Materials Used in Open Loop Systems

All pump surfaces in contact with the fresh water in open loop systems must be bronze or stainless steel. New incoming water and venting to the atmosphere continually oxygenates the water flowing through the collector loop. Steel and cast-iron pumps will corrode, then fail.

TEMPERATURE EFFECTS ON PUMPS

The energy required to circulate each fluid varies according to the temperature. As fluids heat up, the friction of the fluid on the pipe walls is reduced, allowing the pump to move the fluid faster. This offsets the additional flow rate needed to transfer the same amount of heat, as the increase in temperature reduces the fluid's density and heat capacity.

When fluids are cold, higher starting torque will be needed to circulate the fluid. Operating temperatures also affect the pump. As the fluid heats up, entrapped air bubbles may cause cavitation in the pump, deteriorating the pump's impeller and shortening the life of the pump.

PUMP INSTALLATION NOTES

- *The pump is installed in the feed to the collectors and not the return from the collectors. For long pump life, locate the pump on the cold side of the heat exchanger tank.*

- *Isolation flanges or gate valves installed on both sides of the pump simplify pump removal.*

- *Many pumps in antifreeze systems have internal air purgers or the pump should be installed downstream of the air purger so that entrapped air bubbles will be vented. This practice prevents the pump from "cavitating." Expansion tanks should be installed on the suction side of the pump to maintain a constant pressure at the pump.*

- *In nonpressurized draindown and drainback systems, take particular cautions to prevent air bubbles from entering the pump. They will cause cavitation and damage to the impeller. Maintain positive pressure to the supply side of the pump.*

- *Install the pump and controller on a separate 15-amp service line to prevent any possibility of overload and pump failure.*

- *Be certain to mount the pump according to the manufacturer's instructions. Some pump's bearing will burn if the pump is not mounted horizontally.*

- *Check arrows on the pump to see if the flow is in the proper direction. The pressure gauge also will tell you if the impeller is running in the right direction.*

- *Make sure the pump is supported adequately on both sides if necessary. Locate the pump where maintenance will be easy.*

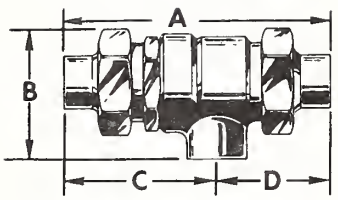
- *Do not insulate pumps.*

- *Avoid sweating male adapters which are already screwed into the pump flange whenever possible. Drops of solder in the pump chamber can jam or destroy pumps and impellers.*

- *Do not run the pump for more than a few seconds without fluid in the system.*

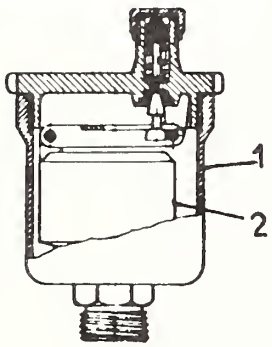
VALVE AND GAUGE SELECTION

Special attention must be given to the selection and placement of valves in a solar DHW system. A variety of the valves and components which are often needed for the safe operation of a solar DHW system are described below. Required components and their settings will vary slightly from one packaged system to another.



Backflow Preventers

An approved backflow preventer on the city water supply may be required in some code jurisdictions for any solar DHW system that uses a nonpotable heat transfer fluid. A check valve is NOT a substitute for an approved backflow preventer and should not be used in its place. Check local codes for requirements in your area. If one is required, use a properly sized polypropylene lined diaphragm expansion tank to compensate for fluid expansion and pipe relief line to a drain.



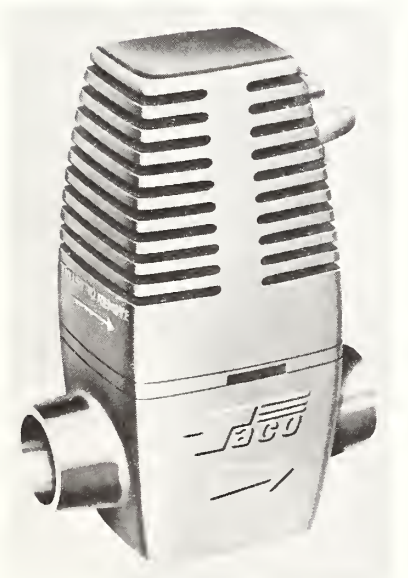
Air Vents

Air vents eliminate air bubbles from the system. Vents are installed at the high points in the system, usually in the collector manifold and above the air eliminator.

Automatic float vents may be used inside only. The cap on the automatic air vent must not be tightened; it should sit loosely on the threads. It is there only to prevent entry of dust or water which would clog the port. The vent MUST be mounted vertically. Outdoors, at the high point in the collector manifold, a manually operated "coin vent" should be used.

Air Eliminators (Air Separator)

An air eliminator also removes air from the heat transfer fluid. The fluid flows across a series of baffles that causes air to bubble up out of the fluid stream. It is then eliminated through an automatic air vent threaded into the top of the scoop. Eliminators usually have fittings that allow for an expansion tank.



Balancing Valves

A balancing valve can be used to control the flow of heat transfer fluids through each collector panel in those systems that do not have a reverse return piping arrangement. Do not use a gate valve for balancing.

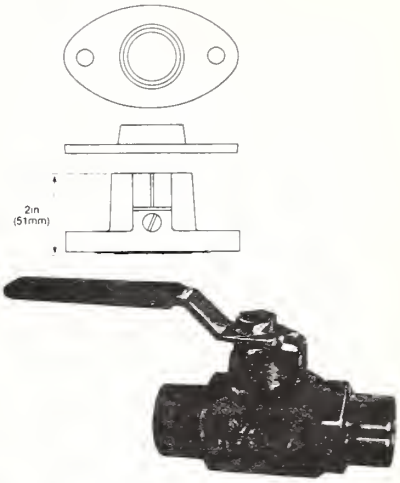
Solenoid Valves

Solenoid valves are electrically operated valves used in draindown systems to start and stop (as well as divert) the flow of heat transfer fluid. Most draindown systems use two such valves: one normally open and one normally closed. When a freezing condition exists or electrical power fails, the valve which allows fluid to circulate to the collectors closes and the valve used to drain the system opens. This procedure is reversed

when the weather is warm and sunny. Solenoid valves require some regular maintenance. In regions with infrequent freezing, its operation should be checked occasionally.

Vacuum Relief Valves

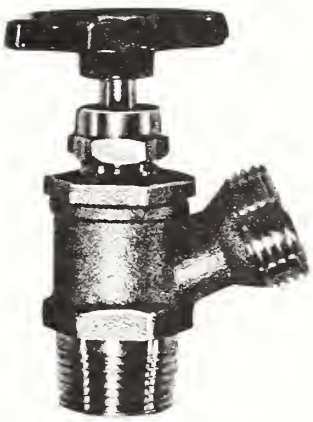
Vacuum relief valves are used in draindown systems and are installed at the high point of the system above the collector. This valve permits the system to drain, using gravity by admitting air into the return piping. It may be required to be installed above the cold water inlet of storage tanks to eliminate vacuum conditions that could collapse the tanks.



Isolation Valves (Shutoff Valves)

Isolation valves should be installed to permit certain components to be serviced without having to drain and refill the system. To avoid unathorized tampering with the system, use tool-operated valves or remove the valve handles and store them in a safe place. Globe valves should not be used because they restrict flow and reduce system efficiency. Isolation valves should be placed at the following locations:

1. One on each side of the circulator pump and strainer (if installed).
2. One at the cold, or city water, supply inlet (to shut down the entire system)
3. One on either side of an external heat exchanger for servicing.



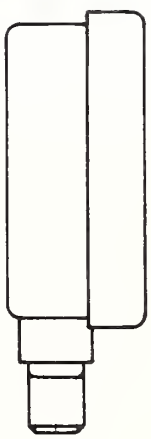
Warning: *Isolation valves should not be installed in a way that could isolate collectors from the pressure relief valve and the expansion tank. This could cause the collectors to burst during stagnation conditions.*

Boiler Drain Valve

There should be one boiler drain valve at the bottom of the storage tank for draining and periodic cleaning. There should also be two on the collector loop near the storage tank. These two valves are used for charging up the system using a pump. They should be separated by a check valve. Install caps (with washers) on the boiler drain outlets.

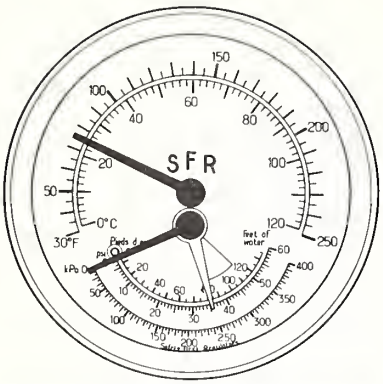
Pressure Gauges

A pressure gauge should be installed on the collector loop or on the eliminator.



Thermometers

Thermometers do not affect system operation. But they do provide useful information to the homeowner and to service personnel. Placing thermometers on the feed and return sides of the solar loop gives an indication of how the system is working. Use button-type thermometers or probe types with diameters of



less than 3/16 inches, they must block less than 20% of the pipe diameter. Thermometers with larger probes can be useful if installed in a proportionately larger fitting. Clamp-on type thermometers can also be used.

Combination Temperature/Pressure Gauges

A combination gauge provides both temperature and pressure information on one instrument.

Elapsed Time Meters

An elapsed time meter can be temporarily or permanently installed to determine how much the system is running and therefore, whether the system is operating properly.

Flowmeters

Flowmeters confirm that there is fluid flowing to and from the collectors. They are available with clear plastic chambers and copper sweat fittings and give system owners a clear indication that the system is running.

Expansion Tanks

An expansion tank is necessary in a closed loop, pressurized system. As the temperature of the heat transfer fluid in the loop rises, the volume of fluid expands. Since liquids do not compress, the expansion tank allows for the expansion of the fluid within the system. If there were no room provided for expansion or contraction, the pressure in the system would fluctuate widely. Expansion tanks are steel or galvanized containers, usually with neoprene or rubber diaphragms bisecting the compartment into an airtight chamber and an open chamber. The open side connects to the fluid loop and the sealed end has a Schraeder valve (air valve). As fluid changes temperature and volume, the bladder compresses the air charge and makes room for expanding fluid. Most tanks come charged from the manufacturer; the valve allows that charge to be either checked or changed.

Installation Of Expansion Tanks

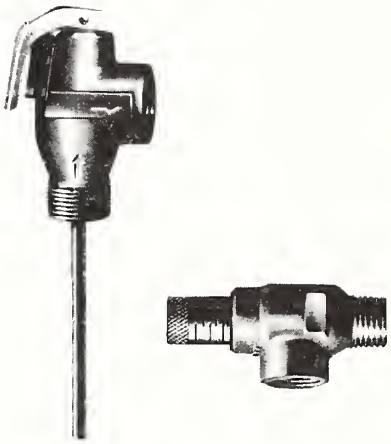
A diaphragm tank can be installed either upward or downward without seriously affecting performance. Downward is preferred to reduce heat loss. The air side of an expansion tank is prepressurized by the manufacturer. If it is necessary to change the air charge in the tank, there is a threaded valve on the tank bottom.

The pressure of the tank depends upon the operating pressure of the system. In general, the tank is pressurized to about two-thirds of the system pressure (after the system has been purged of air). This pressure allows for substantial expansion.

Do not install the tank until after the system is pressure tested because the tank may be damaged during testing. Also, do not

use a galvanized expansion tank with a water/glycol heat transfer fluid. Butyl rubber diaphragms will deteriorate when in contact with oils or water/glycol heat transfer fluids. If glycols are being used, the diaphragm should be EPDM.

Caution: *If the system suddenly loses pressure, do not simply repressurize it. Loss of pressure may indicate a leak in the diaphragm. Check by seeing if liquid will come out the air valve.*



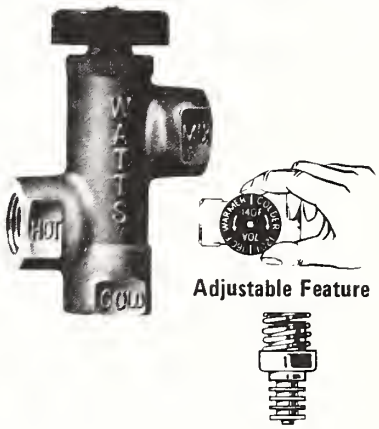
Temperature and Pressure Relief Valves

Temperature and pressure relief valves are similar to pressure relief valves but contain a temperature-sensing element at the valve inlet that must extend into the top of each storage tank, into the hottest water. Valve limits are usually set to 125 psi and 210°F; ratings are listed on the valve. Relief lines from P/T relief valves should be run to within 6 inches of drain.

Warning: *Operating a hot water tank or two tanks in series without a temperature and pressure relief valve is extremely dangerous and is ILLEGAL IN MOST AREAS.*

Tempering or Mixing Valves

This valve is used to add cold water to any flow of water from the storage tank that exceeds a preset temperature, usually between 110° and 140°F. A tempering valve is required on all solar domestic hot water systems to protect users from being scalded. It should be installed 12 inches below the hot water outlet with cold water entering from the bottom. A check valve should be installed to prevent thermosiphoning. The heat-sensing element of a tempering valve must be removed before soldering and replaced afterwards. Soldering temperatures will ruin the sensing element.



Pressure Reducing Valves

Pressure reducing valves are often used to reduce incoming water supply pressure to prevent damage to some components. Pressure reducing valves should be preceded by a strainer and isolated by shutoffs for cleaning.

SIMPLIFIED SIZING PROCEDURES FOR PUMPS AND EXPANSION TANKS

The charts on the next pages are shown for educational purposes only. Contact manufacturers for specific sizing information on their products.

Sizing Pumps for Closed Loop Glycol Systems

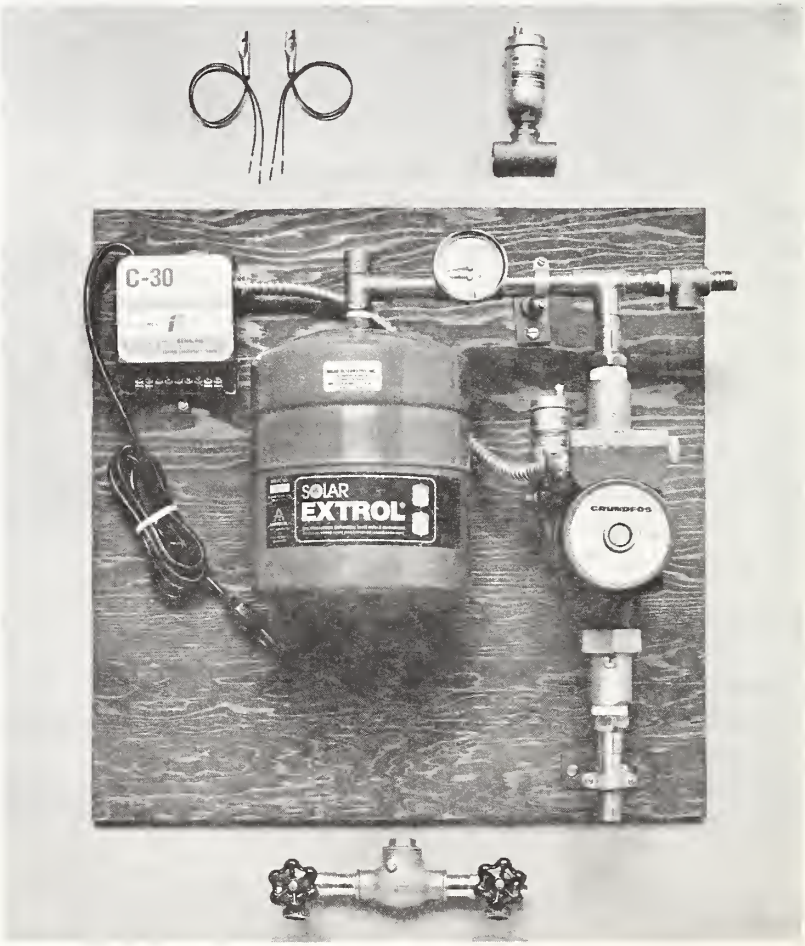
1. Determine Design Flow Rate based on collector area.
2. Determine Head Loss (pressure drop) through the solar loop in feet of head.
3. Select circulator giving sufficient head (Pump discharge pressure) at Design Flow Rate.

Sizing Pumps for Open Loop Systems

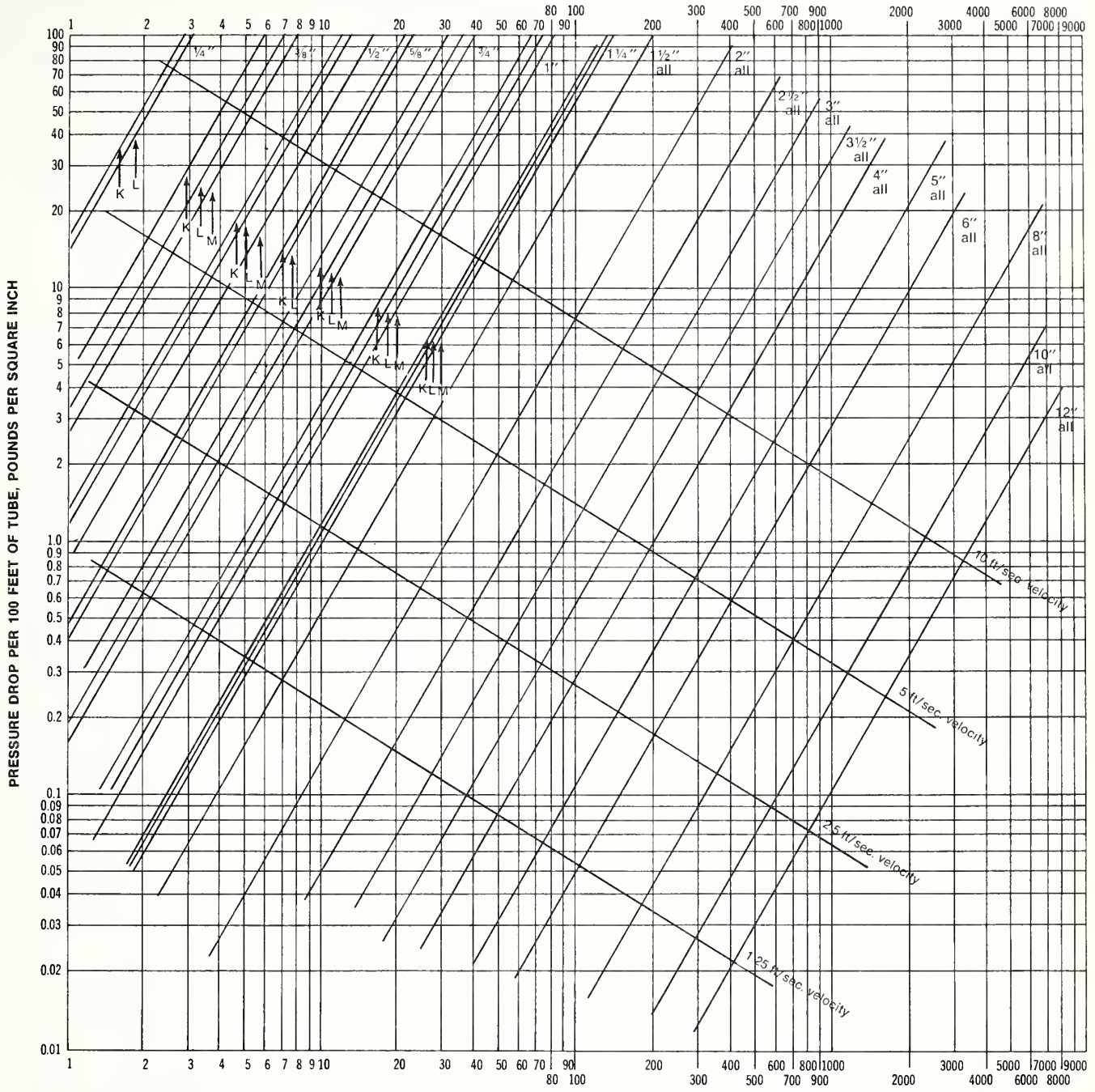
1. Determine Design Flow Rate as above.
2. Determine height in feet water must be lifted to achieve system circulation (Static Head Loss).
3. Determine Head Loss through the system once circulation is achieved (usually equivalent to the Frictional Losses).
4. Select a stainless steel or bronze pump or multi-pump configuration giving sufficient head both to maintain and to initiate circulation.

Sizing Expansion Tanks for Glycol Systems

1. Determine System Volume (by exact calculation, or use a nominal value of 1 gallon per 10 square feet of collector area).
2. Determine System Fill Temperature (lowest expected outside temperature).
3. Determine Average Design Temperature (highest expected stagnation temperature).
4. Determine Minimum Operating Pressure (at expansion tank).
5. Determine Maximum Operating Pressure (at expansion tank — often determined by relief valve setting).
6. Compute Net Expansion Factor (see worksheet).
7. Compute Acceptance Factor (see worksheet).
8. Select Expansion tank(s) following manufacturer's data.



Pressure loss and velocity relationships for water flowing in copper tube



NOTE: Fluid velocities in excess of 5 to 8 ft/sec. are not usually recommended

NET EXPANSION OF ETHYLENE GLYCOL MIXTURE*

(BY VOLUME)

50% ETHYLENE GLYCOL — 50% WATER

FINAL TEMP. (t) °F.	INITIAL TEMPERATURE (T_i) °F.												
	−20°	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
50°	0.0138	0.0121	0.0105	0.0087	0.0060	0.0044	0.0028	—					
60°	0.0165	0.0148	0.0132	0.0115	0.0089	0.0071	0.0055	0.0029	—				
70°	0.0192	0.0175	0.0159	0.0142	0.0116	0.0098	0.0082	0.0056	0.0027	—			
80°	0.0218	0.0201	0.0185	0.0167	0.0145	0.0124	0.0108	0.0085	0.0056	0.0029	—		
90°	0.0245	0.0228	0.0212	0.0195	0.0170	0.0151	0.0134	0.0110	0.0081	0.0054	0.0025	—	
100°	0.0282	0.0265	0.0249	0.0231	0.0204	0.0188	0.0172	0.0144	0.0115	0.0088	0.0059	0.0034	—
110°	0.0310	0.0293	0.0277	0.0260	0.0236	0.0216	0.0199	0.0176	0.0147	0.0120	0.0091	0.0066	0.0032
120°	0.0347	0.0330	0.0314	0.0297	0.0273	0.0253	0.0237	0.0213	0.0184	0.0157	0.0128	0.0103	0.0069
130°	0.0375	0.0358	0.0342	0.0325	0.0308	0.0281	0.0265	0.0248	0.0219	0.0192	0.0163	0.0138	0.0104
140°	0.0413	0.0396	0.0380	0.0363	0.0344	0.0319	0.0303	0.0284	0.0255	0.0228	0.0199	0.0174	0.0140
150°	0.0451	0.0434	0.0418	0.0401	0.0384	0.0355	0.0341	0.0324	0.0295	0.0268	0.0239	0.0214	0.0180
160°	0.0490	0.0473	0.0457	0.0440	0.0422	0.0396	0.0380	0.0362	0.0333	0.0306	0.0277	0.0252	0.0218
170°	0.0529	0.0512	0.0496	0.0479	0.0458	0.0435	0.0419	0.0398	0.0369	0.0342	0.0313	0.0288	0.0254
180°	0.0568	0.0551	0.0535	0.0518	0.0499	0.0474	0.0458	0.0439	0.0410	0.0383	0.0354	0.0329	0.0295
190°	0.0608	0.0591	0.0575	0.0558	0.0543	0.0514	0.0498	0.0483	0.0454	0.0427	0.0398	0.0373	0.0339
200°	0.0648	0.0631	0.0815	0.0598	0.0584	0.0554	0.0538	0.0524	0.0495	0.0468	0.0439	0.0414	0.0380
210°	0.0698	0.0681	0.0665	0.0648	0.0629	0.0604	0.0588	0.0569	0.0540	0.0513	0.0484	0.0459	0.0425
220°	0.0739	0.0722	0.0706	0.0689	0.0672	0.0645	0.0629	0.0612	0.0583	0.0556	0.0527	0.0502	0.0468
230°	0.0780	0.0763	0.0747	0.0730	0.0713	0.0686	0.0670	0.0653	0.0624	0.0597	0.0568	0.0543	0.0509
240°	0.0832	0.0815	0.0799	0.0782	0.0767	0.0738	0.0722	0.0707	0.0678	0.0651	0.0622	0.0597	0.0563
250°	0.0885	0.0868	0.0852	0.0835	0.0818	0.0791	0.0775	0.0756	0.0727	0.0700	0.0671	0.0646	0.0612

FINAL TEMP. (t) °F.	INITIAL TEMPERATURE (T_i) °F.													
	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	230°	240°
110°	—													
120°	0.0037	—												
130°	0.0072	0.0035	—											
140°	0.0108	0.0071	0.0036	—										
150°	0.0148	0.0111	0.0076	0.0040	—									
160°	0.0186	0.0149	0.0114	0.0078	0.0038	—								
170°	0.0222	0.0185	0.0150	0.0114	0.0074	0.0036	—							
180°	0.0263	0.0226	0.0191	0.0155	0.0115	0.0077	0.0041	—						
190°	0.0307	0.0270	0.0235	0.0199	0.0159	0.0121	0.0085	0.0044	—					
200°	0.0348	0.0311	0.0276	0.0240	0.0200	0.0162	0.0126	0.0085	0.0041	—				
210°	0.0393	0.0356	0.0321	0.0285	0.0245	0.0207	0.0171	0.0130	0.0088	0.0045	—			
220°	0.0436	0.0399	0.0364	0.0328	0.0288	0.0250	0.0214	0.0173	0.0129	0.0088	0.0043	—		
230°	0.0477	0.0440	0.0405	0.0369	0.0329	0.0291	0.0255	0.0214	0.0170	0.0129	0.0084	0.0041	—	
240°	0.0531	0.0494	0.0459	0.0423	0.0383	0.0345	0.0309	0.0268	0.0224	0.0183	0.0138	0.0095	0.0054	—
250°	0.0580	0.0543	0.0508	0.0472	0.0432	0.0394	0.0358	0.0317	0.0273	0.0232	0.0187	0.0144	0.0103	0.0049

*Based on derivation by Professor Ferdinand Votta, Jr.,
Department of Chemical Engineering, University of Rhode Island.

CRITICAL SIZING PROCEDURE

The following information relating to expansion tanks refers specifically to "AMTROL" products.

THINGS YOU MUST KNOW:

	METRIC (SI)	ENGLISH
1. Total System Water Content (V_s)	(1) _____ liters	(1) _____ gallons
2. Temperature of water when system is filled (T_f)	(2) _____ °C	(2) _____ °F
3. Average Design Temperature (t)	(3) _____ °C	(3) _____ °F
4. Minimum Operating Pressure (P_f) ..... at EXTROL Tank.	(4) _____ kPa, gauge	(4) _____ PSIG
5. Maximum Operating Pressure (P_f) ..... at EXTROL Tank.	(4) _____ kPa, gauge	(5) _____ PSIG

SELECTION OF EXTROL MODEL:

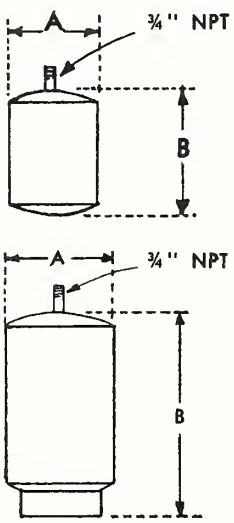
6. Enter Total System Water content (V_s) from Line (1)	(6) _____ liters	(6) _____ gallons
7. Find and enter "Net Expansion Factor":	(7) _____	(7) _____
If Lines (2) and (3) are in °F, use Table 12		
8. Multiply Line (6) by Line (7) to arrive ..... at amount of *Expanded Water*	(8) _____ liters	(8) _____ gallons
9. Find and enter "Acceptance Factor"	(9) _____	(9) _____
If Lines (4) and (5) are in Psig, use Table 6		
10. Divide Line (8) by Line (9) and enter answer here ..... This is *Minimum Total EXTROL Volume.*	(10) _____ liters	(10) _____ gallons

11. If Line 10 is 498 liters (132 gallons) OR LESS: find "AX" Model EXTROL that meets both "Total Tank Volume" (Line 10) and "Acceptance Volume" (Line 8) ..... (11) _____

AX MODEL EXTROL

CAPACITIES (Gallons)

Model No.	Max. Storage Tank Size Max. Water Temp. 140°	160°	180°	200°
AST-5	50	35	25	20
AST-12	100	75	50	45
AST-20	200	150	100	75
AST-30	300	220	150	125
AST-42	400	300	200	150
AST-60	600	440	300	250
AST-80	800	600	450	350
AST-100	1600	1200	900	700



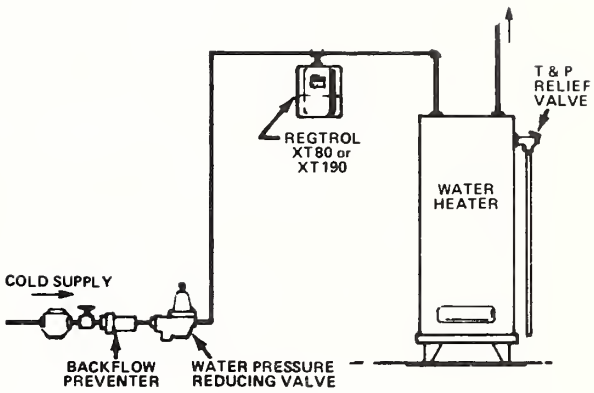
Model No.	Dimensions (Inches) Diam. (A)	Length (B)	Wt. (Lbs.)
AST-5	10¼	8½	26
AST-12	12	11¾	42
AST-20	12	19¼	52
AST-30	16¼	16½	66
AST-42	16¼	23½	106
AST-60	16¼	32	150
AST-80	16¼	42¼	177
AST-100	16¼	81¼	314

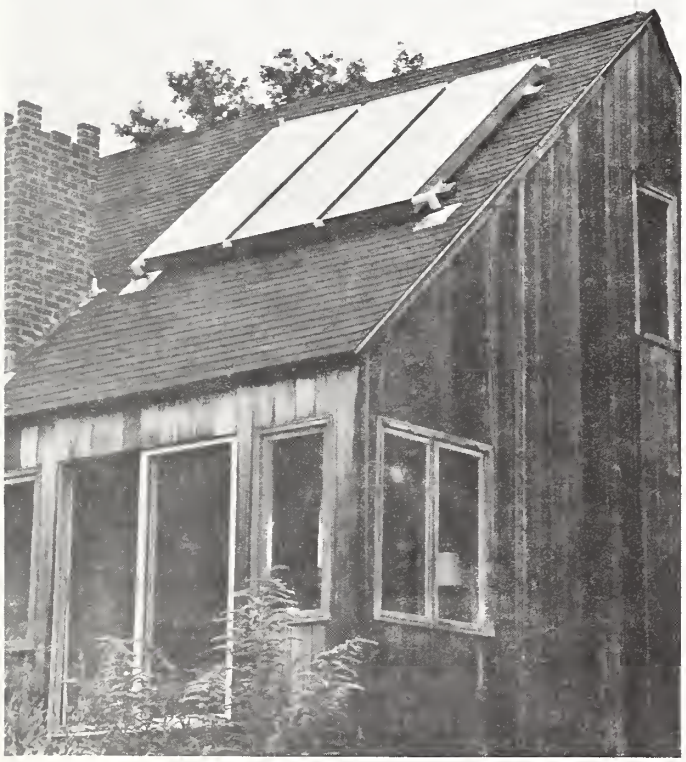
ACCEPTANCE FACTORS $(1-\frac{P_t}{P_o})$

(Use Gauge Pressure)

P_o MAXIMUM OPERATING PRESSURE PSIG	P_t—MINIMUM OPERATING PRESSURE AT TANK (PSIG)											
	5	10	12	15	20	25	30	35	40	45	50	55
10	0.202	—										
12	0.262	0.075	—									
15	0.337	0.168	0.101	—								
20	0.432	0.288	0.231	0.144	—							
25	0.504	0.378	0.328	0.252	0.126	—						
27	0.527	0.408	0.360	0.288	0.168	—						
30	0.560	0.447	0.403	0.336	0.224	0.112	—					
35	0.604	0.503	0.463	0.403	0.302	0.202	0.101	—				
40	0.640	0.548	0.512	0.457	0.366	0.274	0.183	0.091	—			
45	0.670	0.586	0.553	0.503	0.419	0.335	0.251	0.168	0.838	—		
50	0.696	0.618	0.587	0.541	0.464	0.386	0.309	0.232	0.155	0.078	—	
55	0.717	0.646	0.617	0.574	0.502	0.430	0.359	0.287	0.215	0.144	0.072	—
60	0.736	0.669	0.643	0.602	0.536	0.469	0.402	0.335	0.268	0.201	0.134	0.067
65	0.753	0.690	0.665	0.627	0.565	0.502	0.439	0.376	0.314	0.251	0.188	0.125
70	0.767	0.708	0.685	0.649	0.590	0.531	0.472	0.413	0.354	0.295	0.236	0.177
75	0.780	0.725	0.702	0.669	0.613	0.558	0.502	0.446	0.390	0.333	0.279	0.223
80	0.792	0.739	0.718	0.686	0.634	0.581	0.528	0.475	0.422	0.370	0.317	0.264
85	0.802	0.752	0.732	0.702	0.652	0.602	0.552	0.502	0.451	0.401	0.351	0.301
90	0.812	0.764	0.745	0.716	0.669	0.621	0.573	0.525	0.478	0.430	0.382	0.335
95	0.820	0.775	0.757	0.729	0.684	0.638	0.593	0.547	0.501	0.456	0.410	0.365
100	0.828	0.785	0.767	0.741	0.698	0.654	0.610	0.567	0.523	0.479	0.436	0.392
105	0.835	0.794	0.777	0.752	0.710	0.668	0.626	0.585	0.543	0.501	0.459	0.418
110	0.842	0.802	0.786	0.762	0.723	0.682	0.642	0.601	0.561	0.521	0.481	0.441
115	0.848	0.810	0.794	0.771	0.734	0.694	0.655	0.617	0.578	0.540	0.501	0.463
120	0.854	0.817	0.802	0.780	0.742	0.705	0.668	0.631	0.594	0.557	0.520	0.483
125	0.859	0.823	0.809	0.787	0.752	0.716	0.680	0.644	0.608	0.573	0.537	0.501
130	0.864	0.829	0.815	0.795	0.760	0.726	0.691	0.657	0.622	0.586	0.553	0.519
135	0.868	0.835	0.822	0.802	0.768	0.735	0.701	0.668	0.635	0.601	0.563	0.534
140	0.873	0.840	0.827	0.808	0.776	0.743	0.711	0.679	0.647	0.614	0.582	0.550
145	0.877	0.845	0.833	0.814	0.783	0.751	0.720	0.689	0.658	0.626	0.595	0.564
150	0.880	0.850	0.838	0.820	0.789	0.759	0.729	0.699	0.668	0.638	0.608	0.577
155	0.884	0.854	0.843	0.825	0.795	0.766	0.736	0.707	0.677	0.648	0.618	0.589
160	0.887	0.859	0.847	0.830	0.801	0.773	0.744	0.716	0.687	0.658	0.630	0.601
165	0.890	0.863	0.851	0.835	0.807	0.779	0.751	0.124	0.696	0.668	0.640	0.612
170	0.893	0.866	0.855	0.839	0.812	0.785	0.758	0.731	0.704	0.677	0.649	0.622
175	0.896	0.870	0.859	0.843	0.817	0.791	0.764	0.738	0.711	0.685	0.659	0.632
180	0.899	0.873	0.863	0.847	0.822	0.796	0.770	0.745	0.719	0.693	0.668	0.642
185	0.901	0.876	0.866	0.851	0.826	0.801	0.776	0.751	0.726	0.701	0.676	0.651
190	0.904	0.879	0.870	0.855	0.831	0.806	0.782	0.757	0.733	0.709	0.684	0.660
195	0.906	0.882	0.873	0.858	0.835	0.811	0.787	0.763	0.739	0.716	0.692	0.668
200	0.908	0.885	0.876	0.862	0.838	0.815	0.792	0.768	0.745	0.722	0.699	0.675
205	0.910	0.888	0.878	0.865	0.842	0.819	0.796	0.774	0.751	0.728	0.705	0.682
210	0.912	0.890	0.881	0.868	0.845	0.823	0.801	0.779	0.756	0.734	0.712	0.689
215	0.914	0.892	0.884	0.871	0.849	0.827	0.805	0.783	0.762	0.740	0.718	0.696
220	0.916	0.895	0.886	0.873	0.852	0.831	0.810	0.788	0.767	0.746	0.724	0.703
225	0.918	0.897	0.889	0.876	0.855	0.834	0.813	0.792	0.772	0.751	0.730	0.709
230	0.919	0.899	0.891	0.879	0.858	0.838	0.817	0.797	0.777	0.756	0.736	0.715
235	0.921	0.901	0.893	0.881	0.861	0.841	0.821	0.801	0.780	0.760	0.740	0.720
240	0.923	0.903	0.895	0.883	0.864	0.884	0.825	0.805	0.785	0.766	0.746	0.727
245	0.924	0.905	0.897	0.886	0.866	0.847	0.828	0.808	0.789	0.770	0.751	0.731
250	0.926	0.907	0.899	0.888	0.869	0.850	0.831	0.812	0.793	0.774	0.755	0.737

TACO-TROL
PRESSURIZED DIAPHRAGM EXPANSION TANK
MODEL NO. 442


T & P RELIEF VALVE
REGTROL XT80 or XT190
WATER HEATER
COLD SUPPLY
BACKFLOW PREVENTER
WATER PRESSURE REDUCING VALVE



Heat Exchangers

The purpose of a heat exchanger is to transfer the collected thermal energy to the storage system. Heat exchangers used in SDHW systems are either internal or external to the storage tank. The construction is either single or double-wall, depending on the circulating fluid. With non-toxic heat transfer fluids a single-wall exchanger is satisfactory. Toxic heat transfer fluids require a double-wall heat exchanger.

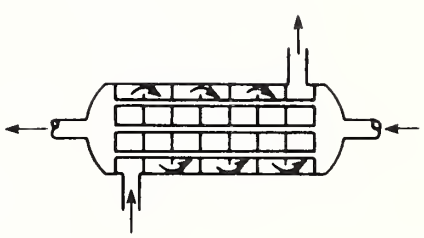
Double-wall heat exchangers must be vented to the atmosphere to indicate any leaks. The heat transfer effectiveness is lower in double-wall heat exchangers due to the additional wall and the air space between the two walls. Double-wall heat exchangers must be sized larger than single-wall heat exchangers to transfer the same amount of heat.

HEAT EXCHANGER MATERIALS

Common heat exchanger materials include steel, copper, aluminum, stainless steel, bronze, and cast iron. The material must be compatible with the system's fluids and piping. Copper, brass, and bronze are used in most solar applications to prevent corrosion of the heat exchanger when aqueous fluids are used. Copper, in particular, is a good thermal conductor and quite versatile.

TYPES OF HEAT EXCHANGERS

Popular heat exchanger designs are tube-in-tube, tube-in-shell, coil-in-shell, spiral coils and coil-in-tank.



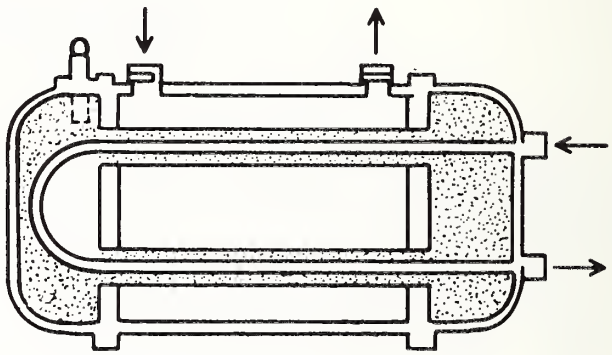
Shell-in-Tube

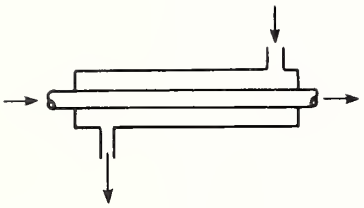
Shell-in-tube heat exchangers are designed differently depending on the number of passes the fluid makes through the heat

exchanger. The tubes and shell should be of the same material. Shell-in-tube heat exchangers are efficient and they are usually a counter-flow design.

Coil-in-Shell

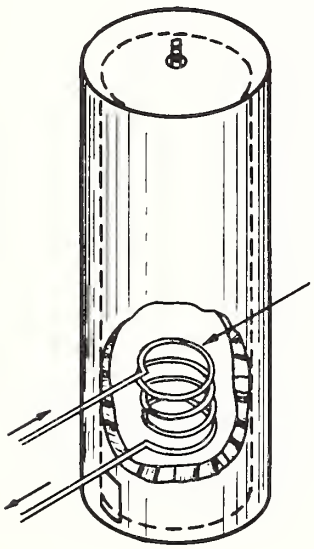
Coil-in-shell heat exchangers have a copper coil inserted into a small steel, copper or stainless steel tank. The heated fluid is circulated through the coil and the cold fluid is circulated through the shell. The fluids flow in opposite directions.





Tube-in-Tube

Tube-in-tube heat exchangers consist of a larger diameter tube centered over a smaller tube. The smaller tube generally has an enhanced surfact to increase heat transfer. The tube-in-tube heat exchanger is one of the most efficient. The fluids through it flow in a counter-flow pattern which means that they flow in opposite directions through the heat exchanger.



Spiral Coils

Spiral coils can be constructed from almost any material. Two sheets of the material are sealed at the edges. Then the sheet is rolled up to form a spiral. The fluids flow in opposite directions through the heat exchangers. This simple design has a very high efficiency.

Coil-in-Tank

Coil-in-tank heat exchangers are unique because they are immersed in the storage tank itself. Heated fluid from the collectors is circulated through the coil. The tank water surrounding the coil is continually heated and rises by natural convection.

EXTERNAL HEAT EXCHANGERS

Heated transfer fluid is pumped into one end of external heat exchangers while a cooler fluid is pumped into the other end.

Each fluid flows through its own separate channel. The warmer fluid transfers the heat to the cooler fluid through the walls of the heat exchanger.

The material and wall surfaces (smooth or finned) conduct the heat between the two fluids. The efficiency and surface area of a heat exchanger can be increased by adding fins to the walls. When the fluids exit the heat exchanger, their temperature difference should be only 5°F to 15°F.

Advantages
External heat exchangers are easy to service, clean or replace if the exchanger fails. They have improved heat transfer per unit and over internal immersed coils, due to the counterflow fluid path. Forced convection heat transfer on both sides of the heat exchanger walls increase their efficiency.

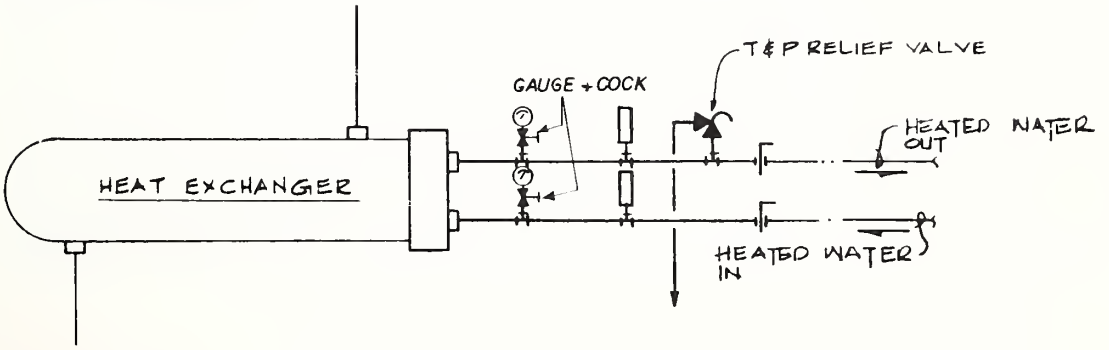
Disadvantages
An additional pump and more electricity is required to circulate the storage fluid through the heat exchanger. Heat is lost to the surrounding area. There is little or no stratification of temperature in the storage tank. Additional piping and wiring is required. The heat exchanger may need to be insulated. A spring type check valve must be installed to prevent thermosiphoning and/or freezing of the heat exchanger.

INTERNAL HEAT EXCHANGERS

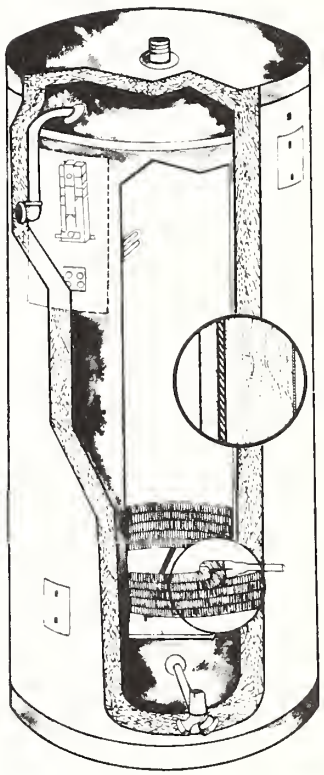
The internal heat exchanger is usually a finned, coiled copper tube. The length of the coil is varied according to the required surface area. Internal heat exchangers are usually located in the bottom of the storage tank. If heat is being removed from the tank, then the coil should be located at the top.

Advantages
They have lower operational heat loss. They encourage stratification of tank temperatures. Less piping and wiring is required. They are conveniently located with no additional installation requirement.

Disadvantages
Internal heat exchanger failure will require replacement of the tank and coil. When the water in the tank is stagnant, heat transfer is reduced.



Storage Tanks



Extensive studies have been done on solar storage by the Solar Energy Group at Argonne National Lab, Argonne, Illinois. Their report "Design and Installation Manual for Thermal Energy Storage" should be read by anyone attempting anything which involves the use of large scale storage tanks. However, much of their work on sizing can be stated in one sentence. For residential space heating and domestic hot water heating systems, storage should be sized to provide from 1.25 to 2.0 gallons of storage per square foot of collector. For air systems, there should be from 50 to 75 pounds of rock per square foot of collectors.

PRESSURIZED TANKS

Standard water heaters are steel tanks that have been designed to store water safely that is under pressure. Larger tanks, above 120 gallons, often are custom designed for specific jobs. The builder should be able to provide for an ASME rating on the tank, and of course, all pressurized tanks should have proper pressure relief valves. For residential and light commercial work, experience has shown that it is often less expensive per gallon to use several 80 or 120 gallon tanks in series or parallel.

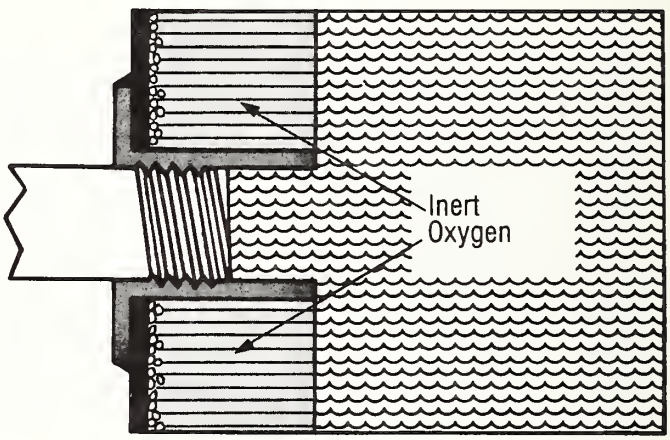
GLASS LINED

Glass lined tanks are composed of a flat sheet of steel that has been rolled into a cylinder, with a spun or stamped top and bottom piece welded on. Since bare steel in contact with oxygenated water (fresh water) corrodes, the steel must be protected. This protection is a glass coating that is sprayed onto the tank and then baked in an oven. However, since this coating may not be perfect or may be damaged during shipping and handling, anode rods are installed. An Anode rod is a "sacrificial" rod that corrodes first, protecting any exposed surfaces in

the tank from corrosion. These rods are designed to be changed, and if they are not allowed to completely disintegrate, the steel will always be protected.

Stone Lined

Stone lined tanks are composed of a flat sheet of steel that has been rolled into a cylinder, with a spun or stamped top and bottom piece welded on. Stone lined tanks are lined with a low-sulfur-content concrete. The tanks are spun to provide a half-inch-thick stone lining. The stone lining protects the wall of the tank by trapping a fine layer of inert oxygen against the tank wall when the tank is filled with water. This layer is held there by the stone lining and the water pressure. Since corrosion needs a continuous supply of oxygen to occur, the tank is protected against corrosion. Because of this, stone lined tanks do not need anode rods.



Stainless Steel

Stainless steel tanks are used for thermosiphon or batch systems. Though their expense is high, they offer longer service lifetimes than glass, or stone lined tanks. More important is that these tanks are much lighter and can be used in applications where tanks are placed on roofs or in attics. While stainless steel does not corrode, extreme care and proper equipment must be used for welding. Stainless steel tanks may need anode rods. Consult the manufacturer for details.

SERVICE TEMPERATURES

Though both glass and stone lined tanks are designed to store water at temperatures up to 200°F, experience has shown that the lifetime of a tank which is operated continuously at high temperatures is significantly shorter than the lifetime of a tank which is operated at temperatures below 160°F. This is because corrosion is sensitive to temperature, and one impact of undersizing storage tanks in solar domestic hot water systems may be shortened tank life.

SUPPLY AND RETURN LINES

In tanks without heat exchangers, proper placement of the supply and return piping is important. Often these tanks have four separate fittings for piping and these should be placed to assure that the coldest water goes to the collectors for heating, and that the hottest water goes to fill the hot water demand. Many manufacturers use dip tubes or diffusers to help maintain stratification.

UNPRESSURIZED SYSTEMS

Large Volume Storage

Note: *The design and specification of large volume steel or fiberglass storage tanks is quite involved. The job should only be approached with proper engineering help from a consultant or tank manufacturer.*

For this discussion, a large volume tank is any tank greater than 120 gallons that is not commonly available and not in mass production. These tanks can have many problems due to their size alone, but they also face the same problems as smaller tanks — how to protect from corrosion and how to prevent heat loss.

Steel Tanks

Some designers are using large volume steel tanks to store their collected energy. Steel tanks must be well protected. If a tank is located in the basement of a structure, the tank can be coated with a primer paint. Then insulation is applied to the tank. Generally, the corrosion of the outside surface is nominal if the surface is properly prepared and the surrounding air is not excessively damp.

The corrosion of the inner tank surface can be more severe. Just like a water heater, the steel tank will be affected by galvanic corrosion. An anode rod must be provided as well as a coating that can endure the degrading effects of hot water and possible additives. Many coatings are available which are advertised to be useful in solar applications.

The installer should consider three main aspects of tank coatings. These are the temperature rating of the coating, the chemical stability to algaecides, rust inhibitors, glycols, etc., and finally, surface preparation and curing time required. Consult the manufacturer before selecting any tank coating whether used on the inside or outside of the tank.

Fiberglass Tanks

With many different grades and types of resins to choose from, the design of a large fiberglass tank is best left up to the tank

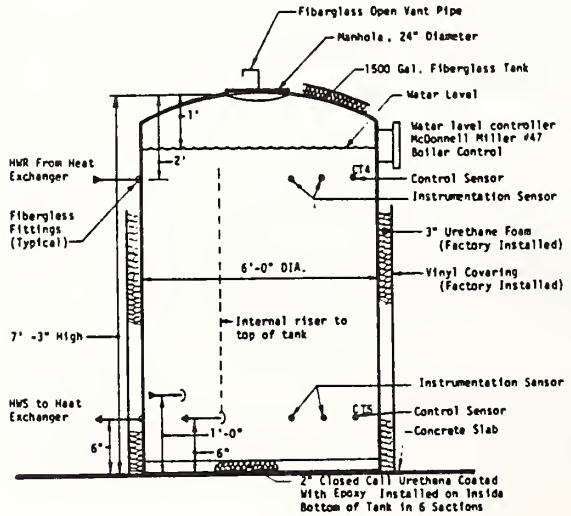
manufacturer. Pre-engineered "off the shelf" tanks often have many problems. The contractors should be aware of these.

A fiberglass or FRP (fiber reinforced plastic) tank offers many advantages over a steel tank if a few precautions are observed. These advantages include lower weight, the ability to do without a tank coating or anodic protection and a slightly reduced cost. Should extra fittings or holes be required on site, the fiberglass or plastic tank can be modified much more easily than steel. No solar storage tank should be made of only orthotalic or isothalic resins (boat resins). These resins are not made to withstand temperatures above 120°F, which are easily obtainable with some systems during both winter and summer.

The tanks should be composed of resins designed specifically for the higher temperatures and aggressive chemical composition associated with solar fluids. Bisphenol-A Tumorates or chlorinated hydrocarbon resins are some of the resins that have been suggested. Some manufacturers will use a mixture of the types of resins in a composite using the higher temperature resins on the inside of the tank while making the rest of the tank out of the less expensive ortho or isothalics. This is reported to work well.

If the tank body was spun or woven and the fittings were layed up by hand, a differential expansion may occur and leaks will follow. If you use a spun tank, all fittings should be flanged, gusseted and drilled to assure a secure mount. A hard contact laminated tank is preferable because leaks are less likely.

Chemical additives in the water storage can also be problematic. Algaecides, rust inhibitors, glycols or anything added to or growing in the water can affect the chemical properties of the fiberglass. Only when the proper type of fiberglass tank is chosen (resin, fiber and construction) will the system last long enough to achieve cost effective economics.



Controllers

The controller is very simple if thought of as a switch, just like a light switch. When the collector is hotter than the storage, the switch flips, turning the pump or blower on. It is as though one finger is on the collector and another finger on the storage, with a brain making the comparison as to which is the warmest surface.

When the control functions are understood, installation becomes a two step process that is very easy. First, the controller box should be near the pump. (It could be mounted anywhere, but near the pump is simpler.) At this point, the 115V electrical connections are made according to the instructions that come with the controller. To make this step easier, some manufacturers provide units with line cords and a plug-in receptacle for the pump cord.

The second step is more difficult than the first, because it involves correct placement and selection of the sensors and selection of differential settings.

CONTROLLER FUNCTION

The job of a controller is to accurately sense the temperatures and manage the system so the maximum number of BTU's are collected. By selection of turn-on and turn-off differentials, which are as low as possible, a greater amount of heat will be gained. However, if the set points are too close together, the controller and pump will short cycle reducing pump life. A five degree "off" will, in most cases, stop this problem.

TYPES OF SENSORS

A basic understanding of different types of sensors that are currently available from various control manufacturers is

necessary to the second step of installation. There are two sensor types, thermistor and wirewound.

Depending upon the specific construction of a thermistor sensor, the top temperature limit is usually restricted to approximately 350°F, whereas the wirebound sensors are capable of higher temperatures. On the other side of the balance, a wirebound sensor's response to a 1°F temperature change is approximately 4 ohms, while a typical thermistor changes approximately 40 ohms.

With the greater ohms resistance response of a thermistor, a controller becomes more accurate, particularly in dealing with lower differential turn-ons and turn-offs. Also, the greater resistance range makes the circuit less vulnerable to aging of internal electronic components or resistance changes due to weathering of the wire connections.

The selection of a type of thermistor is important. Whatever the end fabricated device looks like, they all started out the same as a "thermistor chip." Most thermistor chips are about the size of the "O" on a penny. From this size the themistor sensor is fabricated further only to facilitate physical strength, ease of lead attachment and ease of installation.

SENSOR LOCATION

The collector sensor should be placed where it will sense the hottest point possible, and the storage sensor where it will sense the lowest temperature possible.

The best location for the collector sensor is on the upper manifold inside a flat plate collector. If that is not possible attach it as close to the outlet from the collectors as possible. Care should be taken to thermally insulate the sensor from ambient air so that it will sense only what is intended. A stainless steel hose clamp with a heat transfer compound is recommended for attaching a sensor on an outside pipe.

The best location for the storage sensor on a steel tank is surface mounted, several inches up from the bottom of the tank. When attached directly to the tank, which is in turn covered with fiberglass insulation, a very accurate tank water temperature can be sensed. An alternate position for the storage sensor is at the pipe which leads to the bottom of the collector, right where it exits from the tank. If wire-nuts are exposed to the environment, they should be sealed with silicone.

SENSOR WIRES

The wire leading to the sensors can be anything from 18-2 bell wire (the red and white twisted wire found in most hardware stores) to 24 gauge loudspeaker wire. Some sensor manufacturers recommend shielded cable. Most sensors are designed to withstand temperatures up to 400°F. Do not expose the sensors

to soldering or an open flame. Protect the wire/epoxy end of the sensors from rain. *Never* submerge a sensor.

There can be more than two sensors. Once the two basic sensors are attached there could be, depending on the selected controller, one or more extra sensors to read temperature at different locations.

Run exterior sensor wiring in between the pipe insulation and the exterior jacket. Be careful when using staples or tacks to avoid hitting the wire. Use insulated staples or staples similar to those used by phone installers to fasten sensor wiring inside. "120" volt and "240" wiring should be crossed by sensor wiring at 90's. This is to reduce the possibility of "electrical interference" with the sensor's signal.

FREEZE PROTECTION SENSORS

Solar energy systems with a recirculating or draindown mode for freeze protection will need at least a sensor and a freeze snap switch. These sensors are located as close to the collector inlet and outlet as possible. Additional sensors should be used when there are long pipe runs which could freeze before the collector. The freeze sensors detect the approach of freezing temperatures and any one of them will trigger the controller to turn on the circulator or drain the system. Consult the manufacturer's literature for the sensors and wiring of the controller.
(See the Temperature and Resistance Chart)

SENSOR & CONTROLLER INSTALLATION STEP-BY-STEP

1. Check sensors before installing, using ohmmeter.

At two different temperatures, measured with thermometer, read resistance and compare reading with temperature/resistance curve for those sensors.

2. Install sensors very carefully. If they are to be mounted on copper pipe:

a. Use tube of heat sink (Radio Shack or system supplier). Squeeze tooth-brush quantity on copper, push sensor into it, and tighten screw-driven hose clamp onto sensor.

b. Sensor must be as close to hot area of collector, and tank-bottom, as possible. Sensor must be well insulated, so that it senses tank or collector, not the environment.

c. It is strongly recommended that number 18 stranded communication wire be used with stranded sensor and control wires. If wire nuts are used, tug each wire sharply before sealing.

3. Always check control after installing.

a. Disconnect collector-sensor and tank-sensor leads from control. Attach spare sensors to control. Turn control to "Automatic."

b. Letting substitute tank sensor hang free, squeeze substitute collector sensor in palm of warm hand. Sensor will rise to 90°F and control should turn pump on.

c. With substitute collector sensor still in hand, squeeze substitute tank sensor in other warm hand. Control should turn pump off.

4. To check collector sensor without going on roof:

a. Disconnect lead-wire to collector sensor. Turn control to Manual "on."

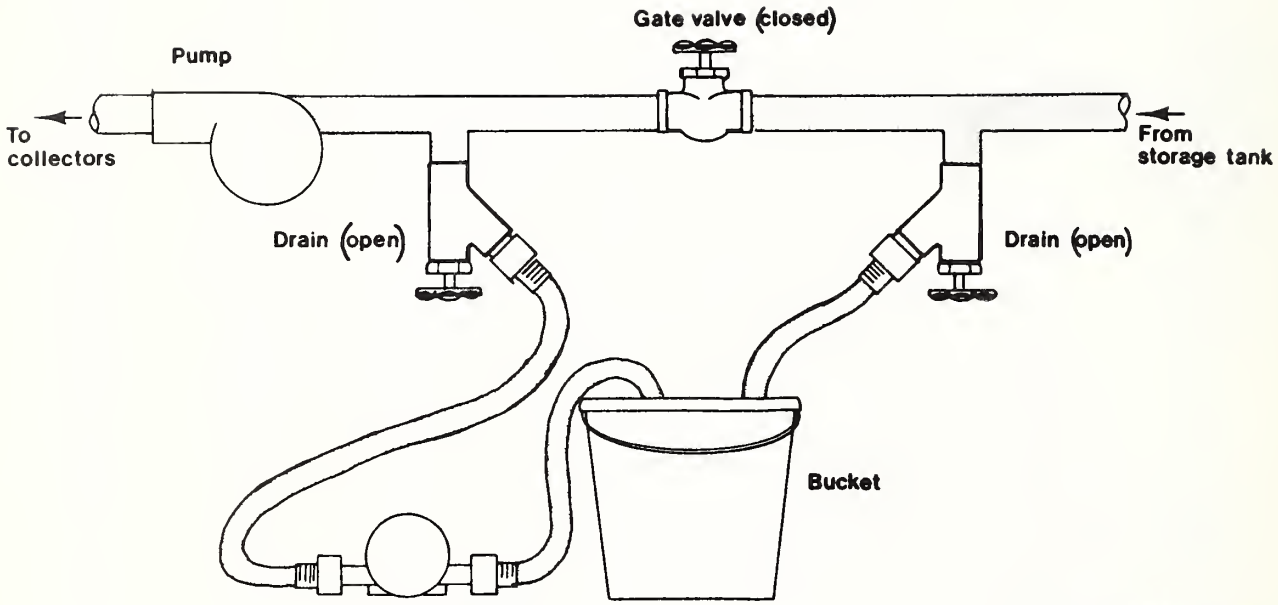
b. Check return water temperature with submersible thermometer. Take ohmmeter reading of collector sensor and refer to Temperature/Resistance curve. Result should be same as return-water temperature.

c. Turn off control. In five minutes, put ohmmeter on collector sensor again. If it is a hot summer day, temperature of collector will rise. On a cool evening, it will fall.

TEMPERATURE VERSUS RESISTANCE CONVERSION CHART

Note: *Temperature readings are in degrees fahrenheit. Sensor readings are Ohms (x 1000).*

3K	°F	10K	3K	°F	10K
70.48	-30	234.0	1.462	108	4.873
49.63	-20	165.4	1.399	110	4.663
35.42	-10	118.1	1.339	112	4.464
25.60	0	85.35	1.282	114	4.274
18.73	10	62.44	1.228	116	4.093
13.86	20	45.19	1.176	118	3.921
10.36	30	34.54	1.127	120	3.757
9.789	32	32.63	1.080	122	3.601
9.251	34	30.84	1.036	124	3.453
8.746	36	29.15	.993	126	3.311
8.272	38	27.57	.953	128	3.176
7.827	40	26.09	.914	130	3.047
7.408	42	24.69	.877	132	2.924
7.015	44	23.38	.842	134	2.807
6.644	46	22.15	.809	136	2.695
6.296	48	20.99	.777	138	2.589
5.968	50	19.89	.746	140	2.487
5.660	52	18.78	.717	142	2.389
5.369	54	17.90	.689	144	2.296
5.095	56	16.98	.662	146	2.208
4.836	58	16.12	.637	148	2.123
4.593	60	15.31	.612	150	2.042
4.363	62	14.54	.589	152	1.964
4.146	64	13.82	.567	154	1.890
3.941	66	13.14	.546	156	1.819
3.748	68	12.49	.525	158	1.751
3.565	70	11.88	.506	160	1.686
3.392	72	11.31	.487	162	1.624
3.229	74	10.76	.469	164	1.564
3.074	76	10.25	.452	166	1.507
2.928	78	9.760	.436	168	1.452
2.790	80	9.299	.420	170	1.400
2.659	82	8.862	.405	172	1.349
2.535	84	8.449	.390	174	1.301
2.417	86	8.057	.377	176	1.255
2.306	88	7.686	.363	178	1.211
2.200	90	7.334	.351	180	1.168
2.100	92	7.000	.294	190	.980
2.005	94	6.683	.248	200	.827
1.915	96	6.383	.210	210	.700
1.829	98	6.098	.179	220	.596
1.748	100	5.827	.153	230	.510
1.671	102	5.570	.113	250	.377
1.598	104	5.326	.085	270	.284
1.528	106	5.094	.065	290	.217



FILLING SOLAR SYSTEM

Filling the System

When the installation has been completed, the system must be checked for leaks. This is usually done before insulating any pipes. If elastomer insulation has been used, it must be removed from all joints so that leaks may be detected.

AIR TESTING

1. Screw down tightly the caps on all air vents or remove them entirely and plug the holes.

2. Remove the expansion tank and plug hole.

3. Make sure all isolation valves (if any) are open.

4. Attach a Schraeder type air valve to the boiler drain of the solar loop.

5. With an air compressor or hand pump, pressurize the system to safe pressure, considering all component ratings. In many systems it is permissible to test at 75 psi, for 15 minutes.

If the system type is not designed for high pressure testing, use a lower pressure — 25 or 30 psi for as long as overnight. A drop of 1-2 psi can be attributed to temperature fluctuation, particularly if pipes have not yet cooled after installation.

6. Leaks can be located with soapy water applied to joints and fittings after the system is pressurized with air. This detailed testing is necessary because many heat transfer fluids will leak where water will not.

7. Particular care must be taken with threaded joints. Leaks at the handle of a boiler drain can be corrected by tightening the stem packing nut slightly. Do not over tighten!

8. When the system is leak tight, drain and depressurize.

FLUSHING THE SYSTEM

1. Flux and solder should be removed from the piping before it is filled with heat transfer fluid. Often the residues from flux and solder are acidic and will shorten the life of the heat transfer fluid if not removed.

2. Two garden or washing machine hoses are needed for flushing. One hose must have two female ends to connect from the water supply to one boiler drain. The other hose connects to the second boiler drain with the loose end near a floor drain.

3. Using the city water pressure, circulate water through the piping system. Normal fill/drain units have a check valve in between the fill/drain which allow fluids to move in only one direction. Using this check valve to isolate the system, fluid can be forced up to the collectors and throughout the entire piping system.

Caution: *The collectors should always be cool when the system is filled. Introducing cold water to hot collectors can cause "thermal shock" damage to the collectors and the piping system.*

FILLING

1. Open all auto-type air vents.

2. To fill, a pump which can produce 50-75 psi should be connected to the fill valve. From the drain valve, a hose can be run into a bucket. The bucket should be filled with more than enough heat transfer fluid to fill the system. *The pump will pump heat transfer fluid up to the collectors and push residual water out of the system. This somewhat diluted heat transfer fluid will be discharged first. Depending on the anti-freeze concentration needed, this fluid can be either dumped or discharged into the bucket thereby slightly diluting the anti-freeze mixture.*

3. Once the fluid becomes "pure" anti-freeze, the discharge hose should be placed in the bucket below the fluid level. The pump should continue to circulate fluid until the fluid clears itself of air.

4. The discharge boiler drain should be closed and the pump run until the system reaches the proper pressure. (Normally the fill boiler drain is closed somewhat so it can be shut down rapidly when system pressure is reached.)

5. For closed loop anti-freeze systems, operating pressure should be set at .46 psi per foot of head, plus 10 psi.

Example: *for a system with the top of the collectors 30 feet above the heat exchanger in the tank, pressure should be set at 30 × .46 psi + 10 or 25 psi total pressure.*

6. After the system is pressurized, the system pump can be turned on.

7. The fill/drain hose is disconnected.

8. The fill and drain can be capped and anti-freeze information tags placed on the system.

GENERAL SAFETY PRECAUTIONS

Solar DHW systems are no more hazardous than conventional domestic hot water systems. Indeed, with a few important exceptions, the safety precautions to be followed in installing, operating, and servicing a solar DHW system are the same as for conventional DHW systems. The major exception is that some solar DHW systems use toxic or nonpotable heat transfer fluids. In this case, you must take particular precautions.

Electrical Safety

Connections and circuit protection at the service box must meet local code requirements. The system controller should have its own properly grounded and protected power outlet. Installation personnel should not stand on a damp floor while working on a circuit. A dry wooden platform should be provided under the service box, and the box should be located far enough from the storage tanks and plumbing so that leaks and drainage will not dampen the floor near it.

Maintenance Personnel Safety

Components should be located to assure safe, easy access to collectors, pumps, storage tanks, and the control system for periodic inspection, maintenance, and replacement. To make maintenance and troubleshooting faster and safer, post a chart near the system listing the appropriate safe pressures, fill levels, flow directions, and other information for all crucial valves and other components. All crucial valves and components should have such information attached on clearly labeled tags, according to HUD's IMPS.

The main fuse should be pulled if work is being done on the service box. When working on one circuit, either remove the fuse or trip the circuit breaker.

Heat Transfer Fluid Safety

Heat transfer fluids should be safe and stable at both stagnation and normal running temperatures. Toxic heat transfer

fluids should be discharged into dry well storage or a sanitary drain in a manner acceptable to local codes. A harmless dye should be added to all toxic or nonpotable heat transfer fluids, if they are not supplied with color added.

All outlets and faucets on nonpotable or toxic fluid lines should be wired, closed and tagged — "DANGER — NOT DRINKABLE." As an added safety precaution, the ends of pipes draining toxic heat transfer fluids SHOULD NOT BE THREADED. This will prevent using hose caps and hookups for domestic usage.

Sample Tag To Be Left on System

This system is filled with _____ .

WARNING: NON-TOXIC FREEZE INHIBITORS MUST BE USED. THE USE OF TOXIC ANTI-FREEZE COULD BE DANGEROUS!

Date filled: _____ Date tested _____
Refill date: _____ System pressure _____
Name of installer _____
Address of installer _____
Phone number of installer _____

There should be an air gap of at least six inches between the end of a pipe which drains toxic heat transfer fluid and the drain. This will prevent any fluid from being siphoned back into the system. If the toxic fluid drain is accessible to children or pets, shield the drain with wire screen or other materials.

An approved backflow preventer at the cold water supply inlet may be required by local codes. The layout of the system must be designed so that direct connection between system wastes and the potable water supply is impossible.

Remember, there must be a double-walled heat exchanger or some other approved method of separating toxic and nonpotable heat transfer fluids from the heated potable water. Single-walled heat exchangers with extra thick walls or those that rely on potable water pressure to prevent contamination are not acceptable to HUD's IMPS.

User Safety

A tempering valve **MUST** be installed to limit the exit temperature of the domestic hot water to under scalding. Brass caps should be used on all drain valves. The vacuum relief valves required to prevent the collapse of storage or expansion tanks must not be allowed to freeze.

SOLAR INSTALLATION CHECK-LIST

COLLECTORS AND MOUNTING

____ 1. Collectors face true south ±20°.
____ 2. Proper Tilt Angle for Purpose.
____ 3. Receive reasonably unobstructed sunlight or surface area has been increased accordingly.
____ 4. Collectors and roof are snow and ice protected.
____ 5. Space is available for inspection and service.
____ 6. Weep holes are properly located.
____ 7. Collectors are rodent protected.
____ 8. Waterflow to and from gutters is unobstructed.
____ 9. Glazing is not cracked.
____ 10. Freeze sensor is well protected & secured.
____ 11. Mounting Hardware is well protected.
____ 12. Dissimilar metals do not touch.
____ 13. All penetrations are adequately sealed and flashed.
____ 14. All exposed wood is treated.
____ 15. Bolt and screw holes are sealed.

Spanners

____ 16. Mounting bolts are ½-inch diameter or greater.
____ 17. Neoprene washers installed.
____ 18. All penetratioons sealed.

Lag Bolt Mounts

____ 19. Bolts are ½-inch diameter or greater.
____ 20. Bolts penetrate rafters.
____ 21. All penetrations sealed.
____ 22. Neoprene washers installed.

Racks

____ 23. Will withstand 100 MPH winds.
____ 24. Properly flashed.

Ground Mounts

____ 25. Bottom of collector is 2 feet above ground.
____ 26. Footings extend below frost-line.

PLUMBING

____ 1. Proper valves are used throughout system.
____ 2. Backflow preventer on potable supply when necessary.
____ 3. No direct connection between potable line and waste line.
____ 4. Double-walled heat exchanger if toxic anti-freeze used.
____ 5. Necessary valves and pipes clearly labeled.

Valves

____ 6. System fully protected against excess pressure and temperature.
____ 7. Pressure relief valves properly installed and piped to drains.
____ 8. Vacuum breakers properly installed.
____ 9. Expansion tank and pressure gauge properly installed.
____ 10. Tempering valve set at 140°F and properly installed on hot water supply line.
____ 11. Check valve installed on cold water supply to tempering valve line.

____ 12. Air vents (coin/float) installed at all high points in system.

Piping

____ 13. No air traps in pipe run.
____ 14. Pipes are properly vented.
____ 15. Expansion joints used if necessary.
____ 16. All threaded joints are teflon taped.
____ 17. All sweated joints are properly soldered.
____ 18. All pipes adequately supported.
____ 19. Joints around collector soldered with 95/5 solder.

SYSTEM CHECK-OUT

____ 1. All valves, gauges, etc., removed and holes secured.
____ 2. System checked at 1½ times the normal operating pressure for at least one hour with collectors covered
____ 3. Drained water carefully measured.
____ 4. All plugs removed & valves, gauges, etc. properly reinstalled.
____ 5. System thoroughly flushed.

INSULATION

____ 1. Properly installed . . . after leak testing.
____ 2. Outside insulation waterproof and UV protected
____ 3. Storage tank insulated.
____ 4. Insulation not impeding any part of system.
____ 5. Pumps, valves, and vents not insulated.
____ 6. Hangers not affecting insulation.

ELECTRICAL

____ 1. Proper sensors installed securely.
____ 2. Sensors protected from ambient air.
____ 3. All wire splices are secure and capped.
____ 4. Outdoor wiring is used where needed.
____ 5. Power input grounded and protected.
____ 6. Proper safety precautions practiced at all times.

GENERAL

____ 1. System filled and pressurized to proper pressure.
____ 2. All work done neatly, carefully, and professionally.

Troubleshooting Guidelines for Closed-Loop Antifreeze Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but liquid does not flow to collectors	Supply valve closed	1. Valve sticks.	1. Repair valve.
	System air-locked	Air vent(s) jammed closed.	Replace vent(s).
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low.	1. Reset according to specifications or setting determined during start-up.
		2. Defective component.	2. Replace thermostat.
		3. Thermostat is out of calibration.	3. Recalibrate.
	Sensor(s)	1. Defective sensor(s).	1. Replace.
		2. Sensor(s) is out of calibration.	2. Recalibrate.
	Control circuitry	1. Bad contacts.	1. Check and correct.

Troubleshooting Guidelines for Closed-Loop Antifreeze Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Repair leaky joint.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp. Replace clamp or hose.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
		2. Gas heater, two-tank systems only. a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment. 3. Both systems a. Thermostat defective. b. Bad contacts.	a. Open manual valve. b. Check and replace. c. Check and replace d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust. a. Replace. b. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective.	1. Replace. 2. Replace.
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting two low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Heater undersized for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner (two-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly sized orifice.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 4. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in sunlit location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
	Collector fluid	1. Antifreeze/water concentration in collector loop fluid is improper. 2. Collector loop degraded.	1. Provide proper insulation. 2. Follow manufacturer's recommendations.

Troubleshooting Guidelines for Closed-Loop Antifreeze Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to improper alignment.	1. Replace 2. Properly align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Air vent the system. 2. Provide adequate pipe support.
	Air vents	Improperly sized.	Install proper air vents.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater, single-tank systems. a. No power to electric heater (single-tank systems only).	a. Check overload protection and correct.
Water temperature too high	Hot water temperature thermostat	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Troubleshooting Guidelines for Drainback Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
Pump runs but water does not flow to collectors	Isolation pump valve(s)	Valve(s) closed.	Open valve(s).
	Pump impeller	Impeller broken or separated from shaft	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low.	1. Reset according to specifications or setting determined during start-up.
		2. Defective component.	2. Replace thermostat.
		3. Thermostat is out of calibration.	3. Recalibrate.
	Sensor(s)	1. Defective sensor(s).	1. Replace.
		2. Sensor(s) is out of calibration.	2. Recalibrate.
	Control circuitry	1. Bad contacts.	1. Check and correct.

Troubleshooting Guidelines for Drainback Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp, replacing clamp or hose if necessary.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in sunlit location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
	Heat exchanger	1. Undersized. 2. Clogged.	1. Install properly sized unit. 2. Clean heat exchanger.
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to misalignment.	1. Replace. 2. Align pump and motor shaft.
	Piping	1. Air locked in the piping. 2. Piping vibrates.	1. Air vent the system. 2. Provide adequate pipe support.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater, single-tank systems. a. No power to electric heater (single-tank systems only).	a. Check overload protection and correct.
		2. Gas heater, two-tank systems only. a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment.	a. Open manual valve. b. Check and replace. c. Check and replace. d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust.
		3. Both systems a. Thermostat defective. b. Bad contacts.	a. Replace. b. Correct.
	Temperature modulating valve	1. Valve defective. 2. Sensor defective.	1. Replace. 2. Replace.

Troubleshooting Guidelines for Drainback Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting two low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Heater undersized for hot water demand	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Burner (two-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correct size orifice.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 4. Replace.
Water temperature too high	Hot water temperature thermostat	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration	Recalibrate or replace.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Troubleshooting Guidelines for Draindown Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Power supply	1. Tripped on overload.	1. Determine cause and replace fuse or breaker.
		2. Open circuit breaker.	2. Check and close.
		3. Defective transformer.	3. Replace.
		4. Line voltage fluctuating.	4. Inform power company.
		5. Brownout.	5. Provide brownout protective device and inform power company.
		6. Control switch on "off" position.	6. Turn to "auto" position.
	Thermostat	1. High and low temperature differential set points too high.	1. Reset according to specifications and/or results obtained during system start-up and testing.
		2. Defective component.	2. Replace thermostat.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor	1. Defective.	1. Replace.
		2. Improper installation.	2. Reinstall.
		3. Defective control cable.	3. Replace.
		4. Sensor out of calibration.	4. Recalibrate.
	Pump	1. Motor failure.	1. Check brush holders, throw-out mechanisms, centrifugal switches, or other mechanical components that may be loose, worn, dirty, or gummy. Replace worn components and reassemble.
		2. Overload protection switch shuts down pump motor.	2. Determine cause of overloading; check if balancing valve is in proper position.
		3. Defective shaft, impeller, or coupling.	3. Replace.
		4. Defective bearings.	4. Replace.
	Control circuitry	1. Circuit continuity lost.	1. Check and repair.
		2. Bad contacts.	2. Check and correct.
	Control circuitry	1. Bad contacts.	1. Check and correct.
System does not drain	Freeze protection thermostat	1. Set point drifted.	1. Reset.
		2. Defective components.	2. Replace.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Recalibrate.
	Sensor(s)	1. Sensor(s) out of calibration.	1. Calibrate.
		2. Defective sensor.	2. Replace.
		3. Improper installation.	3. Reinstall.
	Vacuum breaker	1. Does not open	1. Replace.
		2. Frozen.	2. Add heat tape.
	Drain-down valve closed	1. Actuator defective.	1. Replace actuator.
		2. No power to actuator.	2. Check control wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
System drains continually	Drain-down valve open	1. Actuator defective	1. Replace actuator.
		2. No power to actuator.	2. Check wiring.
		3. Valve sticks.	3. Cycle valve by jumping control system or replace actuator.
	Check-valve	Check-valve leaks.	Isolate valve and replace.
	Freeze protection thermostat	1. Set point drifted.	1. Reset.
		2. Defective components.	2. Replace.
		3. Loose contacts.	3. Tighten wires.
		4. Thermostat is out of calibration.	4. Calibrate.
	Sensor(s)	1. Sensor(s) out of calibration.	1. Calibrate.
		2. Defective sensor.	2. Replace.
		3. Sensor improperly installed.	3. Reinstall.

Troubleshooting Guidelines for Draindown Systems (Continued)

Problem	Components	Possible Causes	Corrective Action
System starts but cycles	Thermostat	High and low temperature differential set points are too close together.	Reset according to specification and/or results obtained during system start-up and testing
	Time delay relay	Time delay "times out" too soon (freeze protection sensor does not heat up in time).	Increase time delay relay setting.
	Control circuitry	1. Circuit continuity lost. 2. Bad contacts.	1. Check and repair. 2. Check and correct.
Pump runs but water does not flow to collectors	Supply valve closed	1. Actuator defective. 2. No power to actuator. 3. Valve sticks.	1. Replace actuator. 2. Check wiring. 3. Cycle valve by jumping control system or replace actuator.
	Draindown valve open	1. Actuator defective. 2. No power to actuator. 3. Valve sticks.	1. Replace actuator. 2. Check wiring. 3. Cycle valve by jumping control or replace actuator.
	System air-locked	Air vent(s) jammed closed.	Replace vent(s).
	Pump impeller	Impeller broken or separated from shaft.	Replace impeller and/or shaft assembly.
	Blocked liquid flow passage	Pipe damaged.	Replace damaged section.
System runs continuously	Thermostat	1. Low temperature differential set point set too low. 2. Defective component. 3. Thermostat is out of calibration.	1. Reset according to specifications or results obtained during start-up. 2. Replace thermostat. 3. Recalibrate.
	Sensor(s)	1. Defective sensor(s) 2. Sensor(s) is out of calibration	1. Replace. 2. Recalibrate.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Heater failed to actuate	1. Electric heater (single-tank systems). a. No power to electric heater (single-tank systems only). 2. Gas heater (double-tank systems only). a. Failure to ignite (gas off). b. Safety switch malfunctioning. c. Defective thermocouple and/or automatic pilot valve. d. Pilot won't stay lit. 1 Too much primary air. 2 Dirt in pilot orifice. 3 Pilot valve defective. 4 Loose thermocouple connection. 5 Defective thermocouple. 6 Improper pilot gas adjustment. 3. Both systems. a. Thermostat defective b. Bad contacts.	a. Check overload protection and correct. a. Open manual valve. b. Check and replace. c. Check and replace. d. 1 Adjust pilot shutter. 2 Open orifice. 3 Replace. 4 Tighten. 5 Replace. 6 Adjust. 1. Replace. 2. Correct.
	Mixing valve (double-tank systems only)	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace.

Troubleshooting Guidelines for Draindown Systems (Concluded)

Problem	Components	Possible Causes	Corrective Action
Hot water temperature not high enough	Hot water thermostat	1. Thermostat setting too low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Undersized heater for hot water demand.	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joint.
	Hose connections	Clamp does not hold tight.	Tighten up the hose clamp. Replace clamp or hose.
	Relief valve	1. Improper pressure setting. 2. Defective component.	1. Check pressure setting and correct. 2. Replace.
Poor solar energy collection	Collector array	1. Undersized collector area. 2. Collectors shaded 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in more appropriate location. 3. Rebalance flow. 4. Flush collector loop. 5. Repair.
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair.
System noisy when operating	Pump cavitation	1. Restricted pump suction line. 2. Air in the system.	1. Remove restrictions. 2. Manually vent the system if automatic air vents are not adequate.
	Pump bearings	1. Bearing worn. 2. Bearing damaged due to improper alignment.	1. Replace. 2. Properly align pump and motor shaft.
	Air vents	Improperly sized.	Install proper air vents.
	Burner (double-tank systems only)	1. Burner clogged. 2. Undersized burner orifice.	1. Clean. 2. Provide correctly-sized orifice.
	Mixing valve (double-tank systems only)	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace
Water temperature too high	Hot water temperature	1. Thermostat seeting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Sensor	Out of calibration.	Recalibrate or replace.
	Mixing valve (double-tank systems only)	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.

Source: Argonne National Laboratory: Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Troubleshooting Guidelines for Thermosyphon Systems

Problem	Components	Possible Causes	Corrective Action
System does not start	Piping	Pipe blocked.	Remove blockage to the water flow.
System leaks	Pipe joints	1. Thermal expansion and contraction. 2. Joint improperly made.	1. Provide flexibility and reassemble. 2. Reassemble leaky joints.
	Hose connection	Clamp does not hold tightly.	Tighten up the hose clamp. Replace clamp or hose
	Relief valve	1. Improper pressure setting. 2. Defective component. 3. Designer did not provide enough space for the thermal expansion in the storage tank.	1. Check pressure setting and correct. 2. Replace. 3. Drain excessive water out of the storage tank.
No hot water	Make-up water shut-off valve	Valve closed.	Open valve.
	Electric heater	No power to electric heater.	Check overload protection and correct.
	Auxiliary heater thermostat	1. Thermostat defective. 2. Bad contacts.	1. Replace. 2. Correct.
	Auxiliary heater sensor	1. Sensor out of calibration. 2. Sensor defective.	1. Recalibrate. 2. Replace.
	Mixing valve	1. Valve defective. 2. Sensor defective. 3. Leak in capillary tubing.	1. Replace. 2. Replace. 3. Replace
Hot water temperature not high enough	Auxiliary heater thermostat and/or overheat protection thermostat	1. Thermostat setting too low. 2. Thermostat out of calibration.	1. Set thermostat higher. 2. Recalibrate or replace thermostat.
	Auxiliary heater	Undersized heater for hot water demand.	Replace when heater fails.
	Safety switch	Set too low.	Check and reset.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too low. 3. Valve spring too weak.	1. Recalibrate. 2. Reset. 3. Replace.
Water temperature too high	Hot water temperature	1. Thermostat setting too high. 2. Thermostat out of calibration. 3. Bad contacts.	1. Reset. 2. Recalibrate. 3. Correct.
	Temperature modulating valve	1. Sensor out of calibration. 2. Temperature set too high.	1. Recalibrate. 2. Reset.
	Sensor	Out of calibration	Recalibrate.
Poor solar energy collection	Collector array	1. Collector area undersized. 2. Collectors shaded. 3. Flow rate too high or too low. 4. Heat transfer surface covered with scale deposits. 5. Leaks.	1. Install more collector area. 2. Remove obstacle or install collectors in more appropriate location 3. Rebalance flow. 4. Flush collector loop. 5. Repair
	Piping	1. Insufficient insulation. 2. Improper weather protection. 3. Insulation damaged. 4. Undersized piping between storage tank and collector. 5. Piping partially blocked.	1. Add additional insulation. 2. Provide proper weather protection. 3. Repair. 4. Install adequate piping. 5. Flush piping runs.

Source: Argonne National Laboratory. Interim Reliability and Materials Design Guidelines for Solar Domestic Hot Water Systems, ANL/SDP-9; Solar/0907-80/70

Books and Products List

Suppliers, grouped according to the products and equipment they offer and some useful reference books are listed below. A more complete product listing can be found in the Energy Products Specification Guide published by SolarVision Publications, Church Hill, Harrisville, NH.

The editors of this book can assume no responsibility for the validity of manufacturer's statements, nor do we endorse any products included in this list. It is a wise practice to check the background of a company before doing business with them. Talk to people who know them about their experience with that company, how the company deals with problems and about their service and product record.

BOOKS

Active Solar Energy Systems Design Practice Manual
Solar/0802 — 79/01 Technical Information Center
Department of Energy
P.O. Box 63
Oak Ridge, TN 37830 1979

ASHRAE Handbook of Fundamentals
ASHRAE Sales Department
345 E. 46th Street
New York, N.Y. 10017 1977

The Design and Installation Criteria — Residential
Tennesse Valley Authority
715 Market Street, Rm 320
Credit Union Building
Chattanooga, TN

Design and Installation Manual for Thermal Energy Storage
(Design of liquid and air storage, more emphsis on large systems)
Argonne National Laboratory
9700 South Case Avenue
Argonne, IL 60439 1979

Engineer's Guide to Solar Energy
Yvonne Howell and Justin A. Bereny
Solar Energy Information Services
San Mateo, CA 94401 1979

Final Reliability and Materials Design Guidelines for Solar Domestic Hot-Water Systems
(A close examination of all parts of the system)
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439 1981
ANL/SDP-11, Solar/0909-81/70

The Glass Glazed Site-Built Collector Manual
(A Construction Manual for building Liquid Collectors)
Solar Alternative Inc.
71 Main Street
Brattleboro, VT 05301 1982

Insolation data Manual
SERI/SP — 755 — 789, October, 1980
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401 1980

Model — TEA Solar Heating System
(A Construction Manual for building Air Collectors)
Total Environmental Action. Inc.
Church Hill
Harrisville, N.H. 03450 1982

Solar Energy Fundamentals in Building Design
(A general descriptive book with useful tables)
Bruce Anderson
McGraw-Hill
New York, N.Y. 1977

Solar Energy Thermal Processes
(Solar heat transfer in mathematical form)
Duffie and Beckman
John Wiley & Sons, 1974

Uniform Solar Energy Code
International Assoc. of Plumbing & Mechanical Officials
Los Angeles, CA 1976

PRODUCT SUPPLIERS LISTED BY EQUIPMENT

Circulating Pumps

Company: **Armstrong Pumps, Inc.**
93 E. Avenue North
Tonawanda, NY 14120 716-693-8813
Housing Material: cast iron or bronze
Impeller Material: noryl

Company: **Grundfos Pumps Corp.**
2555 Clovis Avenue
Clovis, CA 93612 209-299-9741
Horsepower: 1/35 to 5
Housing Material: stainless steel or cast iron
Impeller Material: stainless steel

Company: **Hartell Div. of Milton Roy Co.**
70 Industrial Dr.
Ivyland, PA 18974 215-322-0730
Horsepower: 1/150 to 1/150
Housing Material: bronze
Impeller Material: glass reinforced PPS, stainless steel & ceramic

Company: **ITT Bell & Gossett**
8200 N. Austin
Morton Grove, IL 60053 312-667-4030
Horsepower: 1/12 to 1 1/2
Housing Material: cast iron or bronze
Impeller Material: non-ferrous

Company: **March Mfg., Inc.**
1819 Pickwick
Glenview, IL 60025 312-729-5300
Horsepower: 1/200 to 1/5 DC models available
Housing Material: bronze, cast iron or plastic
Impeller Material: stainless steel or plastic

Company: **Myson, Inc.**
P.O. Box 5025
Embrey Industrial PK
Falmouth, VA 22401 703-371-4331
Horsepower: 1/25 to 1/20
Housing Material: cast iron or bronze
Impeller Material: stainless steel

Company: **Richdel, Inc.**
P.O. Box Drawer-A
1851 Oregon Street
Carson City, NV 89701 702-882-6786
Horsepower: 1/30
Housing Material: glass filled polysulfone and thermal plastic
Impeller Material: glass filled polysulfone and thermal plastic

Company: **Taco, Inc.**
1160 Cranston Street
Cranston, RI 02920 401-942-8000
Horsepower: 1/25 to 1/12
Housing Material: cast iron
Impeller Material: stainless steel

Company: **Thrush Products, Inc.**
P.O. Box 228
Peru, IN 46970 317-472-3351
Housing Material: cast iron
Impeller Material: bronze

Company: **Dayton Electric Mfg.**
5959 W. Howard St.
Chicago, IL 60648 312-647-8421
Horsepower: 1/100
Housing Material: bronze
Impeller Material: ryton

Piping Accessories

Company: **Amtrol, Inc.**
1400 Division Rd.
W. Warwick, RI 02893 401-884-6300
Comments: air vents, expansion tanks, air purgers, valves etc.

Company: **Blue White Ind.**
14931 Chestnut Street
Westminster, CA 92683 714-893-8929
Comments: Flow meters

Company: **Combraco Industries, Inc.**
P.O. Box 125
Pageland, SC 29728 803-672-6161
Comments: valves, water gauges, air cocks, etc.

Company: **Hammond Valve Corp.**
1844 Summer Street
Hammond, IN 46320 219-931-3200
Comments: valves, etc.

Company: **Hedland Products**
Division of Racine Federated
2200 South Street
Racine, WI 53404 414-639-6770
Comments: Flow meters

Company: **Letro Thermometer, Inc.**
8311 Airport Road
Redding, CA 96001 916-365-5424
Comments: Thermometers

Company: **Metraflex Co.**
2323 W. Hubbard Street
Chicago, IL 60612 312-738-3800
Comments: valves, etc.

Company: **Milwaukee Valve Co., Inc.**
2375 S. Burrel Street
Milwaukee, WI 53207 414-744-5240
Comments: valves etc.

Company: **Mueller Brass Co.**
1925 Lapeer Ave.
Port Huron, MI 48060 313-987-4000
Comments: valves, fittings, etc.

Company: **Nibco, Inc.**
Simpson Ave
Elkhart, IN 46515
valves, fittings, etc.

Company: **Phelps Dodge Brass Co.**
Lee Brothers-Div. of Phelps Dodge Industries, Inc.
P.O. Box 1229
Anniston, AL 36202 205-831-2501
Comments: valves, fittings, etc.

Company: **Red-White Valve Corp.**
22527 S. Wilmington Avenue
Carson, CA 90745 213-549-1010
Comments: valves etc.

Company: **Watts Regulator Co.**
10 Embankment Street
Lawrence, MA 01942 617-688-1811
Comments: valves etc.

Pipe Insulation

Company: **Armstrong Cork Co.**
Dept.12-WHP
P.O.Box 3001
Lancaster, PA 17604 717-397-0611
Product: Armaflex
Material: 3/8", 1/2", 3/4" thick elastomer
Temperature Range: -40° to +220°F
Product: Armalok II
Temperature Range: -100°F to +220°F

Company: **Benson Insulation Company**
12 Elm Street
Hatfield, MA 01038
Product: R-7 Insolpipe
Material: 5/8" -24" in all wall thicknesses
Comments: R = 7.679 UV inhibited bronze & white — ASJ

Company: **Certain Teed Corp.**
P.O.Box 860
Valley Forge, PA 19482
Product: 500° Snap On
Material: 1/2" thru 4-1/2" fiberglass
Temperature Range: -20° to +500°F
Comments: PVC covering and sheet insulation available

Company: **Halstead Industrial Products**
Division of Halstead Industries, Inc.
P.O. Box 309
Wynne, AR 72396 501-238-3201
Product: Insul-Tube
Material: 3/8", 1/2", 3/4" elastomer
Temperature Range: -40° to +220°F
Comments: adhesive, exterior coatings and sheets available

Company: **Insultek Corp.**
82 Crestwood Road
Rockaway, NJ 07866
Product: R-7+
Material: 3/4", 1", 1-1/2" isocyanurate
Comments: preinsulated pipe; PVC jacket in white or bronze

Company: **Knauf Fiber Glass GMBH**
Shelbyville, IN 46176
Comments: Fiberglass, up to 6" thickness and 30" ID

Company: **Northeast Specialty Insulation, Inc.**
520 Broadway
Lawrence, MA 01841 617-688-1162
Product: Solar 7
Material: Isocyanurate
Comments: R-7/in.; UV inhibited PVC jacket; sheet & spray foam available.

Company: **Rovanco Corp.**
I-55 & Frontage Road

(*continued,* Rovanco Corp.)
Joliet, IL 60436 815-726-0640

Product: Insul-8
Material: 1″ to 5″ polyurethane
Temperature Range: -350° to +300°F
Comments: Preinsulated pipe; PVC jacket

Company: **Rubatex Corp.**
Bedford, VA 24523 703-586-2611
Temperature Range: -40° to +220°F

Company: **Teledyne Mono-Thane**
1460 Industrial Pkwy
Akron, OH 44310 216-633-6100
Product: Foamedge
Material: 1/2″ polyurethane foam
Temperature Range: to 250°F
Comments: UV inhibited vinyl jacket

Heat Transfer Fluid

Product Name: **Brayco 888 F**
Generic Fluid: Synthetic Hydrocarbon
Company: Bray Oil Co.
9550 Flair Drive
Suite 301
El Monte, CA 91731 213-575-1212
Temperature Range: °F: -50 to +450°
Toxicity: No

Product Name: **Dow Frost**
Generic Fluid: Inhibited Propylene Glycol
Company: Dow Chemical
Midland, MI 48640 517-496-5985
Temperature Range: °F: -60 to 450
Toxicity: No

Product Name: **Freon 114**
Generic Fluid: Complex Fluoromethane (gas)
Company: Dupont Co.
1007 Market Street
Wilmington, DE 19898 302-774-2549
Toxicity: No

Product Name: **Inhibited Propylene Glycol Douglas**
Generic Fluid: Propylene Glycol
Company: Douglas Chemical
Route 3, Box 180
Liberty, MO 64068 816-781-4250
Temperature Range: -40 to +600°
Toxicity: No

Product Name: **Norkoo Peak**
Generic Fluid: Ethylene Glycol & Corrosion Inhibitors
Company: Northern Petrochemical Co.
2350 E. Devon
Des Plains, IL 60018 800-323-2300
Temperature Range: °F: to +260
Toxicity: Yes

Product Name: **Solar Winter Ban**
Generic Fluid: Aqueous Propylene Glycol
Company: Camco Manufacturing
121 Landmark Drive
Greensboro, NC 27409 919-668-7661
Temperature Range: °F: -55 to +400°
Toxicity: No

Product Name: **Sunsafe (200 series)**
Generic Fluid: Propylene Glycol
Company: National Patent Development/Energy Systems
1455 Research Blvd.
Rockville, MD 20850 301-424-4870
Temperature Range: °F: -30 to +225
Toxicity: No

Product Name: **Sunsol 60**
Generic Fluid: Aqueous Propylene Glycol
Company: Sunworks
P.O. Box 508
Windsor, CT 06095 203-688-5432
Temperature Range: °F: -55 to +400
Toxicity: No

Product Name: **Syltherm 444**
Generic Fluid: Poly Dimethyl (silicone)
Company: Dow Corning
Midland, MI 48640 517-496-5985
Temperature Range: °F: -50 to +400
Toxicity: No

Product Name: **UCAR Thermofluid 17**
Generic Fluid: Inhibited Ethylene Glycol
Company: Union Carbide Corp.
P.O. Box 65
Tarrytown, NY 10591 914-345-3578
Temperature Range: °F: -33 to +300
Toxicity: Yes

Storage Tanks:

Company: **A. O. Smith Corp.**
P.O.Box 28
Kankakee, IL 60901 815-933-8241
Capacity: 66, 82, 100, 120, to 1,000 gallon models
Tank Shell: Steel TANK LINING: glass lined
Insulation: Foam Fiberglass (R-16)
Heat Exchangers: Internal double wall copper coil; electric element

Company: **Bradford-White Co.**
24th & Ellsworth Street
Philadelphia, PA 19146 215-546-3800
Capacity: 65, 80, 120 gallon models
Tank Shell: Steel TANK LINING: vitraglas lined
Insulation: Polyurethane (R-12 to 16)
Heat Exchangers: electric element

Company: **Ford Products Corp.**
Ford Products Road
Valley Cottage, NY 10989 914-358-8282
Capacity: 40, 65, 80, 120 gallon models
Tank Shell: Steel TANK LINING: stone lined
Insulation: Fiberglass (R-8.6)
Heat Exchangers: various sizes; electric element

Company: **Mor-Flo Industries Inc.**
18450 S. Miles Road
Cleveland, OH 44128 216-663-7300
Capacity: 52, 66, 82, 120 gallon models
Tank Shell: Steel TANK LINING: glass lined

(*continued,* Mor-Flo Industries Inc.)
Insulation: Polyuretane (R-16)
Heat Exchangers: External system module

Company: **Rheem/Rudd Water Heater Divisions**
5780 Peachtree-Dunwoody Road, N.E.
Atlanta, GA 30342 404-256-2037
Capacity: 66, 82, 120 gallon models
Tank Shell: Steel TANK LINING: glass lined
Insulation: Polyurethane
Heat Exchangers: not used; direct drainback into tank, air compressor maintains air space in the top of the tank.

Company: **State Industries Inc.**
Cumberland Street
Ashland City, TN 37015 800-251-8170
Capacity: 82, 120 gallon models
Tank Shell: Steel TANK LINING: glass lined
Insulation: Fiberglass
Heat Exchangers: four internal heat exchanger chambers, also serve as a reservoir when water in collectors drains back; electric element.

Larger Volume Storage Tanks

Company: **Acorn Structures**
Box 250
Concord, MA 01742 617-369-4111
Capacity: 300, 800, 2,000 gallons
Tank Material: galvanized steel with vinyl linner
Insulation: fiberglass R-11 R-19

Company: **Badger Solar**
549 South Riverview Road
Franklin, WI 53132 414-529-1031
Capacity: 95, 200 gallons
Tank Material: 11 ga. steel with epoxy coated.

Company: **Lifetime Tank**
5000 Packinghouse Road
Denver, CO 80216 303-295-2700
Capacity: 550-15,000 gallons
Tank Material: Fiberglass

Company: **Ondrusek Solar Supply**
300 West Park Avenue
Myerston, PA 17067 717-866-5163
Capacity: 90 gallons
Tank Material: High density seamless polyethylene

Company: **Raven Industries**
P.O. Box 1007
Sioux Falls, SD 57117
Capacity: 150-600 gallons
Tank Material: Fiberglass

Company: **STSS Company**
477 Woodcrest Drive
Mechanicburg, PA 17055
Capacity: 210-1800 gallons
Tank Material: Site built walls with EPDM linner

Company: **State Industries, Inc.**
Cumberland Street
Ashland City, TN 37015 800-251-8170
Capacity: 82, 120 gallon models
Tank Shell: steel TANK LINING: glass lined
Insulation: Polyurethane
Heat Exchanger: not used; direct drainback into tank air compressor maintains air space in the top of tank.

Heat Exchangers

Company: **Alstrom Corp.**
140 S. Seabury Ave.
Bronx, NY 10461 212-824-4901
Flow Design: tube-in-shell, double wall, 2 & 6 pass
Material: steel shell & copper tubes

Company: **Doucette Industries, Inc.**
Heat Transfer Div.
P.O. Box 1641
York, PA 717-845-8746
Flow Design: concentric tube, double or single-wall, counter-flow
Material: copper tubes

Company: **Elanco, Inc.**
Box 172
Landenberg, PA 19350 215-274-8936
Flow Design: double spiral, single-wall, counterr flow
Material: stainless steel, copper, carbon steel, others available

Company: **H & H Tube & Mfg. Co.**
Suite 495
4000 Town Center
Southfield, MI 48075 313-355-2500
Flow Design: tube-in-tube, double or single-wall, counter-flow
Material: copper

Company: **Hydro-Flex Corp.**
2101 N.W. Brickyard Rd.
Topeka, KS 66618 913-233-7484
Flow Design: immersed coil, single-wall
Material: corrugated copper

Company: **ITT, Fluid Handling Div.**
4711 Golf Rd.
Skokie, IL 60076 312-677-4030
Flow Design: tube-in-shell
Material: steel shell, copper tubes

Controllers

Company: **Dan-Mar Co., Inc.**
10319 Wikel Rd.
Huron, OH 44839 419-433-4479
Comments: 1 to 6 inputs, 1 to 5 outputs, digital display, freeze protection

Company: **Hi Square Inc.**
2611 Old Okeechobee Rd.
W. Palm Beach, FL 33409 305-686-8400
Comments: 2 to 4 inputs, 1 to 2 outputs, proportional, 110 & 240 VAC

Company: **Heliotrope General**
3733 Kenora Drive
Spring Valley, CA 92077 619-460-3930
Comments: 2 to 3 inputs, 1 to 4 outputs, 3-K sensors, adj. differential, temperature monitor, pool controllers & valves

Company: **Independent Energy, Inc.**
42 Ladd Street
E. Greenwich, RI 02818 401-884-6990
Comments: Microprocessor based, 2-6 inputs, 1 to 4 outputs, remote digital display, programmable, priority pool/dhw

Company: **Natural Power, Inc.**
Francestown Tpk.

(continued, Natural Power, Inc.)
New Boston, N.H. 03070 603-487-5512

Comments: Built-in metering and test, ac or dc, 2 to 3 inputs, 1 to 2 outputs.

Company: **Richdel, Inc.**
P.O. Drawer A
Carson City, NV 89701 702-882-6786

Comments: 1 to 3 inputs, 1 to 2 outputs

Company: **Rho Sigma**
1800 W. 4th Street
Hialeah, FL 33010 305-885-1911

Comments: 1 to 4 inputs, 1 to 4 outputs, , adj. differential

Company: **Solar Control**
2524 E. Vine Dr.
Ft. Collins, CO 80524

Comments: 2-3 inputs, 1-5 outputs

Company: **Solarmetrics**
160 Bouchard Street
Manchester, NH 03103 603-668-3216

Comments: Sensor test circuits, 2 to 3 inputs, 1 output, remote digital display

Devices For Solar Access Measurement

Company: **Solar Pathfinder™**
Solar Pathways, Inc.
Valley Commercial Plaza
Glenwood Springs, CO 81601 303-945-6503

Comments: The reflected image of all shadow-casting objects is displayed on the surgace of a transparent, reflecting dome. The full year's data is contained in a single image. Diagrams cover 5° latitude bands.

Company: **Sunbloc™**
Pacific Sun, Inc.
437 Tasso St.
Palo Alto, CA 94301 415-328-4588

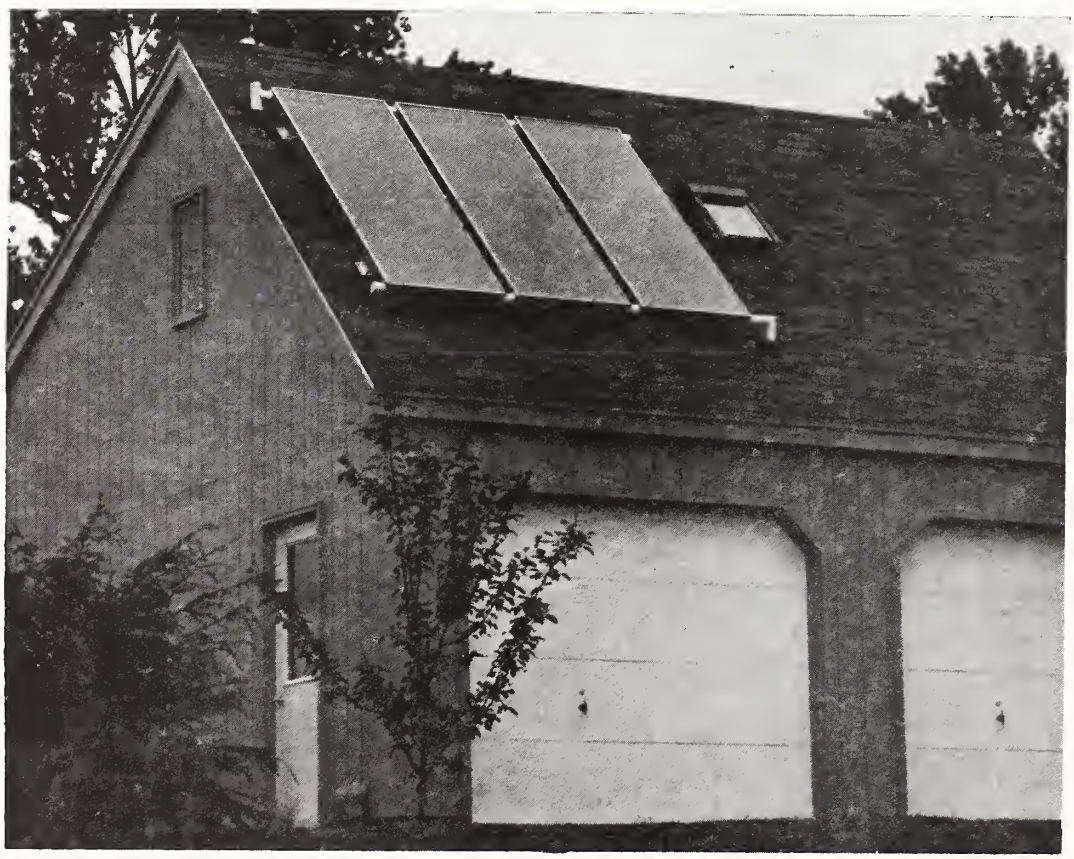
Comments: A Brunton handled transit is supplied to observe the angle elevation of each shading object. Sequential readings at various azimuth angles enable measurement of all shadow patterns.

Company: **Solar Site Selector**
Lewis and Associates
105 Rockwood Srive
Grass Valley, CA 95945 916-272-2077

Comments: Sunpaths are printed on transparent grids. Siting through a "distortion optic" enables coincident viewing of shading optics and sunpaths. Covers 2° bands.

Company: **Suns Angle Calculator**
Zomeworks
P.O. Box 712
Albuquerque, NM 87103 505-242-5354

Comments: Shading objects and transparent sunpath grid are coincidentally lighted in a plane mirror, horizontally mounted at the center of the instrument. Successive sightings at various angles builds a "horizon plat."



Domestic Hot Water Installations:

The Great, the Good, and the Unacceptable

Skilled inspectors have checked every detail of 170 solar domestic hot water installations in the Northeast. Their conclusions? Most systems are working just fine, but some problems crop up alarmingly often. Here's a guide to preventive troubleshooting for sellers and buyers.

By Jack Meeker and Lew Boyd

The most thorough analysis of installed solar domestic hot water systems ever attempted began in November 1980. The Northeast Solar Energy Center (NESEC), one of the four regional solar authorities working under a contract with the U.S. Department of Energy, enlisted the National Association of Solar Contractors, Inc. (NASC) to help with the project. The purpose of the program was to investigate the state of the art of installation techniques and system durability in the field.

All together, 170 residential solar water heating systems were evaluated in the six New England states, New York, New Jersey, and Pennsylvania. The systems chosen were installed by professionals, had been in service for between one and two years, and proportionally represented the sales activity of various manufacturers in each state.

Six teams of inspectors made the evaluations. Each team consisted of a technician representing the Northeast Solar Energy Center and a NASC contractor. Technicians had a minimum of three years of solar experience. Each contractor had installed over 100 solar domestic hot water systems prior to joining the Site Evaluation Program. The teams received evaluation training at NESEC and were equipped with a full array of diagnostic instruments. They first conducted pilot field inspections to test a specially prepared, 12-page checklist and to ensure that each team conducted its surveys uniformly. The final surveys took place between November 1980 and February 1981, with the crews spending an average of two and one-half hours at each site.

The findings and recommendations of the Site Evaluation Program (SEP) are summarized here for the first time. Many thousands of items checked at the 170 installations were tabulated by computer. Data from the field inspections will be contained in the complete report. The report will include an executive summary outlining major findings, sections on methodology, marketing and economics, and a listing of manufacturers participating by state.

Of the 170 systems inspected, 50 percent were rated as excellent or good in overall workmanship. Over 88 percent were satisfactory in terms of system operation. Some 31 systems were judged to be "Red Stars"—i.e., outstanding. The table below describes the types of systems evaluated:

Closed loop (antifreeze)	156
Drainback	11
Draindown	2
Phase change	1

The overall findings do substantiate that solar domestic hot water heating is technically proven and can effect significant savings even in the climatically rigorous Northeast, if systems are properly installed.

Nevertheless, the study uncovered many recurrent problems in the field. Solar professionals and prospective consumers of solar domestic hot water systems can learn much by studying the report and recommendations of the site evaluation team. The report should prove especially worthwhile for contractors entering the solar field.

Categories marked with an asterisk (*) below indicate areas where errors can severely impair overall performance of the system or create potential hazards. Unmarked categories deserve close attention, too, but these problems were not considered to be as serious.

The installation problems identified in this study led the site evaluation team to recommend that installer certification be considered for the solar industry.

Jack Meeker is the Active Solar Program Manager at the Northeast Solar Energy Center and directed the Site Evaluation Project. Lew Boyd is president of Boyd Associates, Bedford, Mass., and a co-founder of the National Association of Solar Contractors, Inc. Photos are from the Northeast Solar Energy Center.

Orientation and Tilt Angles of Collectors *

Although the overall focus of the program was not system performance, inspectors did reach an informal consensus on orientation and tilt angles: azimuths far off true south (over 45°) and tilt angles under 30° or over 55° appear to impair solar contributions. Systems with azimuths of 60°, for example, do not receive adequate direct radiation, especially during the winter. Systems with tilt angles less than 30° so favor summer performance in the Northeast that snow will not shed in winter.

The watch points true south at solar noon. The performance of DHW systems with collectors oriented at less than optimal azimuths like this one ought to be measured authoritatively.

Recommendations: The industry has been willing to install solar energy systems within wide tilt and azimuth parameters. This issue deserves careful and authoritative study. Performance compromises should be analyzed on a month-by-month basis, given deviations in azimuth from true south, in tilt from an angle equal to the local latitude, and in storage-to-collector ratios. Actual Btu output of comparable equipment and equal demand should be monitored. The validity of computer simulations now in wide use should be verified against these very basic site parameters.

Shading

Shading, mostly by trees, during collector hours was reported in 35 percent of the cases studied, but it was not considered severe in most instances. Still, contractors and homeowners do not have a clear enough understanding of the penalties of shading or of how to predict its occurrence. In a few cases where the collectors themselves caused shading, a sawtooth configuration had been used without sufficient space between the panels.

Sawtooth configurations can lead to shaded collectors when the panels are not spaced properly. The collector in the rear is partly shaded during the early hours of each collection period.

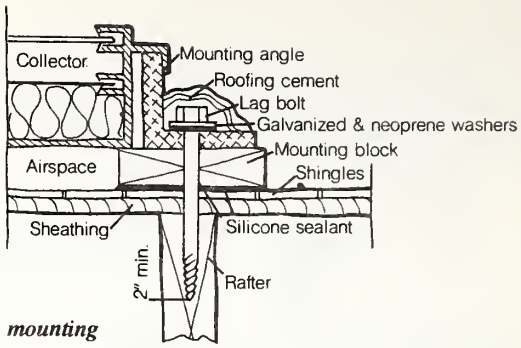
Recommendations: The *HUD Installation Guidelines for Solar DHW Systems* should be followed in all but exceptional cases; i.e., no more than five percent of the collectors should be obstructed between 9:00 A.M. and 3:00 P.M. on an annual basis. Manufacturers should provide siting tools and instructions for their installers.

Collector Mounting *

In roof-mounted collector systems, 32 percent had one or more of the following problems: "flier" (insufficiently attached); wood deterioration; evidence of leaks; dissimilar metals in contact; insufficient spanners/blocking; lag bolts into sheathing only; materials with inadequate strength; spanner not affixed to rafters; or other difficulties.

Many racks seen in the project appeared to be one of a kind. Some were under-designed, others over-designed. As of the end of 1979, few manufacturers offered pre-engineered rack designs and materials.

The most pressing concern of the inspection teams was the actual attachment of the collectors to the roof. Lagging into sheathing only is absolutely unacceptable. If blocking beneath sheathing is not attached to neighboring rafters, the blocks' resistance to uplift forces is reduced drastically. If spanners are not attached to adjacent rafters they can move into the rafter bay.

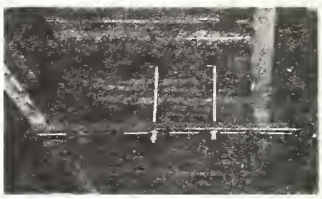


Lag-bolt mounting

Recommendations: Manufacturers should accept the responsibility of providing fully engineered mounting and rack details suited to the collectors they produce. Similarly, installers must recognize that there are only three techniques considered acceptable for collector and/or rack mounting: spanner, direct lagging into rafters, and blocking. Spanner and lagging techniques are fully described in the HUD solar guidelines. If site considerations preclude the use of these techniques, which are preferable, then blocking is an alternative. A block is cut to fit exactly into each rafter bay where an attachment will be made. The block of a 2 x 6-inch lumber is soundly toed into the rafters with nails. The lag screws or thread rod are then brought through the sheathing, and finally through the blocking as secondary support.

Roof Support *

Homeowners and solar installers sometimes have a hard time judging whether or not a roof is strong enough to support collectors. The inspection teams were given tables of wind and snow loading parameters as they relate to rafter size and spacing, which are part of the Massachusetts State Building Code. The sites were measured against these tables. In 19 cases the roof support was judged to be inadequate. It is interesting to note that only in Massachusetts were certain sites found to have reinforced roof structures under the solar energy system.



The roof here is shored up with additional rafters to support the collector load. The installation also shows an excellent spanner mount. Unistrut stretches from rafter to rafter and is soundly toed in. The threaded rods are attached with two nuts.

Recommendations: All states should follow the example set by the Commonwealth of Massachusetts, which furnishes tables reflecting its particular roof loading parameters.

Use of Wood *

Wood takes extreme punishment when it is exposed to the sun, water, and other weather conditions. Wood has shown signs of thermal degradation when used in collector frames or housings. Untreated wood should not be used in collector mounting, whether in sleepers and standoffs or full-scale collector stands.

Untreated wood should never be used in rack-mounted roof systems like this. The rack is also straddling the roof ridge, secured only by the feed and return piping to the collectors.

Recommendations: Racks fabricated from similar metals are preferred to wood for reasons of longevity. If wood must be used, all wood components should be pressure-treated and fully accessible for service.

Condensation and Outgassing

Condensation in collectors can reduce the thermal quality of the insulation over time. This condition also causes much concern among homeowners. Outgassing can severely reduce the transmissivity of cover glazing. Of the reporting cases, about 20 percent had evidence of condensation in one or more collectors. One in eight of the systems studied showed collector outgassing.

Outgassing and condensation are related to certain brands of collectors. The manufacturers should correct such defects.

Recommendations: Condensation and outgassing tended to occur in certain brands of collectors. A correlation appears to exist between condensation and the use of urethane collector insulation. This problem points to manufacturers rather than installers. Makers should give these problems more attention, and installers should carefully check the record of the manufacturers.

Corrosion

Most corrosion noted in the SEP involved screws, nuts, bolts, and other fasteners used to hold panels together. Plating of the hardware was often deteriorating. There was no meaningful correlation with time—manufacturers had not made significant progress in this area by late 1979 when compared with early 1978.

Corrosion shown here on the collector housing is a manufacturer's flaw. Corrosion appearing on the mounting standoff is the contractor's fault. When corrosion on the standoff worsens, the collector can become a "flier."

Recommendations: Collector manufacturers should give considerable attention to the fasteners they use outdoors. Compatible, weather-resistant materials must be used. Particular attention should also be given by the installer to the use of compatible materials in the mounting of collectors.

Sensors

The teams paid close attention to sensor placement, attachment, wire splicing, etc. Most collector sensors that could be seen were installed properly. Those that appeared safest, however, were attached to the absorber plate by manufacturers using a screw or a rivet. These sensors were completely protected from ambient air conditions and moisture.

In a few cases solar tank sensors were mounted improperly. Adequate tank/sensor thermal contact is necessary. Sensors should not be affixed to the cold water inlet instead of the tank, nor to the solar loop itself.

Recommendations: Because the controller subsystem is critical to system operation, correct placement and installation of sensors is the key. More manufacturers should consider factory installation of collector sensors. Whenever sensors are factory mounted, built-in trap doors should be supplied to provide easy access for servicing. This technique will also allow spliced wire connections to be protected from ambient weather conditions.

In this installation sensor wire to the thermistor is exposed to ambient moisture, which will find its way into the splice and fool the controller. The safest sensors are those attached to the absorber plate by the manufacturer.

It is also recommended that manufacturers or packagers provide specific installation instructions as to where and how to mount tank sensors. Tank manufacturers should provide mounting clips in the appropriate spot. These clips should be easily accessible for installation and service in the field.

Piping and Penetration

Poor piping configurations and inadequate materials can impair system performance. Improper techniques used in penetrating the building envelope with piping can result in damage to the structure. A variety of problems appeared in this area.

Some 29 systems were piped as "C-flow," where both supply and return piping is at one end of the collector array. In systems with more than two collectors, this arrangement frequently results in thermal imbalance across the array.

In almost one fifth of the systems visited, the collectors were undrainable. A similar number of systems were reported to have loop piping that did not meet accepted pipe hanging standards.

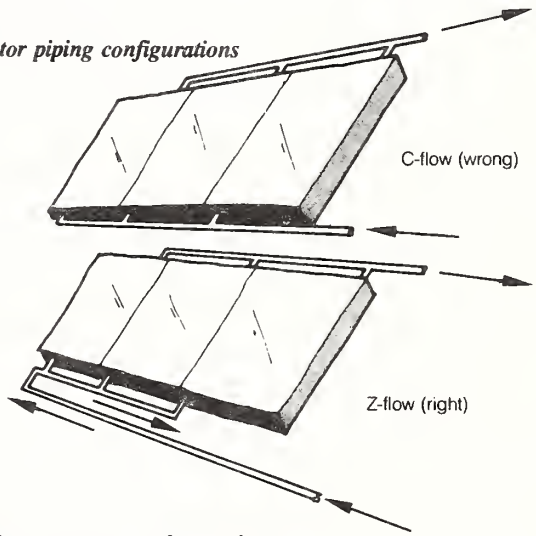
Eight systems studied used CPVC for the solar loop. Of these, seven were observed to have unacceptable distortion and waving in the loop.

Finally, and perhaps most importantly, 20 percent of the sites studied included solar loop penetrations into the building envelope that were judged unsatisfactory because they permitted water to leak to the inside.

The snug-fitting, shoe-type penetration is recommended for clean and water-tight piping on roof-mounted domestic hot water systems.

Recommendations: For standardization and simplicity, all solar energy systems, regardless of the number of collectors, should be installed using "Z-flow," (reverse-return) configuration. Whenever possible, collectors should be piped so that they can self-drain. When this is impossible, a manual drain should be installed at the collector low point.

Collector piping configurations



C-flow systems (top) frequently create thermal imbalance across the array. The Z-flow (bottom) configuration, or reverse-return, is better for all solar energy systems.

The SEP team recommends close adherence to the *HUD Installation Guidelines for Solar DHW Systems*, which provides

strict standards for hanging techniques and intervals for copper tubing and threaded pipe. In this study, rigid plastic pipe (CPVC) did not appear appropriate for solar DHW applications. The distorted piping observed was apparently losing rigidity under high loop fluid temperatures. If, after further investigation, CPVC is found to be able to withstand typical solar loop temperatures over time, new standards for hanging techniques and intervals need to be established.

Watertight penetrations for piping are critical to the quality and durability of an installation. The SEP team recommends the use of the no-caulk roof shoe used often and successfully by the building industry. If proper 1-inch-wall insulation is used over the piping, a 2-inch roof shoe fits snugly over the insulation, giving an easy, clean penetration. Small holes in the roof can be treated with silicone sealant, which can be placed around the roof shoes for extra protection.

Pipe Insulation

One of the most recurrent problems encountered was the insufficient quality of loop insulation. The problems fall into three areas: R-value, sealing, and ultraviolet degradation. The site evaluation team found that the industry falls far short of the *HUD Installation Guidelines*, which call for minimum insulation of R-4 on all solar loop piping, R-6 on pipe of 1-inch diameter or greater. Elastomer is used widely but the thickest wall size reported was ¾-inch, which affords an R-value of less than half the HUD recommendations. Insulation must be properly closed and sealed. The elastomer insulation in many systems had been slit and placed over the piping after the piping had been installed. Shrinkage of the insulation then often exposed large gaps. Sealing is critical on outside loop piping, where temperature differentials are great. Small slits and cracks worsen over time with intermittent exposure to sun, rain, snow, and ice. Sealing all seams with silicone or mastic seems to outlast all other techniques.

Elastomer insulation has undergone dramatic ultraviolet degradation in this system. Materials should be selected for solar transport systems based on their ability to withstand exposure to weather and ultraviolet radiation.

The investigation of 102 systems using elastomer insulation outside pointed conclusively to the fact that this material is not suitable for the application. In virtually every case, some ultraviolet degradation was noted. Some contractors seal outside insulation with ordinary paints. These coatings generally do not hold up well; deterioration was dramatic. Metal claddings, ultraviolet-inhibited PVC jackets, and "do-all" jackets, on the other hand, all appear to be lasting well.

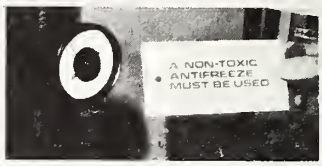
Recommendations: The team strongly recommends that the industry as a whole concentrate on insulation of solar transport systems. In terms of R-value, the *HUD Installation Guidelines* minimum of R-4 must be followed. One-inch thicknesses of urethane, fiberglass, and phenolic foam are among the few pipe insulations readily available that conform to this requirement. Other materials, such as elastomer, must be avoided. Much more attention should be given to sealing insulations to maintain thermal quality and weather protection outside. Manufacturers and installers should also understand the effect of ultraviolet light on outside insulation and select materials on this basis.

Heat Transfer Fluids *

Propylene and ethylene glycol antifreeze solutions occasionally become acidic, although ethylene glycol solutions appear to be the more stable of the two. No correlation was found with factors like length of operation or system size to explain why particular systems turned acidic. But in 39 percent of the systems using a controller that features a high limit shut-off, propylene glycol was reported at pH 6.5 or less. Allowing fluid to boil in stagnating collectors appears to contribute to pH degradation.

In all four systems that used glycerin, the pH balance was acidic. There was no evidence of abnormal stagnation exposure in these systems or any special factors that might have contributed to the problem.

Six of the seven silicone-oil-charged systems showed signs of some leakage, especially at threaded connections and around the air purger assembly. Yet, the seepage was not severe. The lowest loop pressure reported for these seven systems was 15 psi, which was satisfactory given the short distance from the tank to the top of the collectors.



Over 50 percent of the domestic hot water systems inspected in the project had no labels to indicate what heat transfer fluid was used. Labels are vital for service and safety.

The freeze strength of ethylene and propylene glycol-charged loops was measured in 128 systems. Freeze strengths of less than −21°F were considered too weak in the rigorous climate of the Northeast. Some 34 percent of the systems were inadequate. Most of the antifreeze solutions were presumably supplied pre-mixed by manufacturers to achieve a freeze level of at least −40°F. The team inspectors theorize that installers, instructed by the manufacturer to flush the loop with water after piping it, are not purging all of the water from the loop before charging it with antifreeze. Simply opening boiler drains at the solar tank would be insufficient in many cases where undrainable low spots in the loop were noted. In four systems the weakness of antifreeze was easily explained. The contractor had left a washing-machine-type hose connected between the incoming cold water supply and the fill/drain assembly on the solar loop. Homeowners were told to open the valves and let some street water into the loop whenever the solar loop pressure dropped below 10 pounds.

Despite warning signals, it is noteworthy that none of the antifreeze systems visited had frozen up.

Finally, over half of the systems inspected had no labeling to indicate what heat transfer fluid was used.

Recommendations: The problem of glycols becoming acidic deserves further study. However, controllers with upper limit shut-offs should not be used with glycol systems. The team recommends that pH balance of all glycol systems be checked, along with the freeze strength, once a year. Whenever the solution drops below a pH of 6.5, it should be changed. Manufacturers who wish to use glycerin should perform careful time, temperature, and pH studies. Otherwise, they should instruct installers to be prepared to change the fluid often. Manufacturers and packagers who supply silicone oils with their systems should pay more attention to helping contractors install leak-proof loops.

Installers should be careful to drain the flushing water from loops. All low spots in closed-loop systems must have drains. Upon filling and purging a system with a glycol solution, freeze strength must be checked with proper equipment and noted on the fill label attached to the system. Unlabeled systems are unacceptable from a safety and service point of view. The team recommends full and immediate adherence to the *HUD Intermediate Property Standards*. Contractors should fill in tags provided by manufacturers with their equipment describing installation date, fluid type, quantity, pH, and freeze point.

Valves and Vents *

The team studied 156 closed-loop systems. Of 128 systems reporting, 30 percent did not have pressure relief valves on the solar loop to allow antifreeze to escape if maximum allowable pressure were exceeded. Of these systems, 53 percent were produced by one system manufacturer. The team was surprised to find *any* systems

without pressure relief valves. This lack represents a safety hazard in clear violation of all national plumbing codes. Slightly over 10 percent of 163 cases reporting had no temperature/pressure relief valve on the storage tank. Failure to install such relief valves constitutes the most severe safety hazard in the solar plumbing trade. Almost one half of the systems investigated did not have tempering valves, permitting the possibility of severe scalding. Finally, over one fifth of the closed loop systems did not have proper air vents at the collector high point.

This air vent at the collector high point is incorrectly positioned. Air vents should be perpendicular to the ground, not perpendicular to the collector.

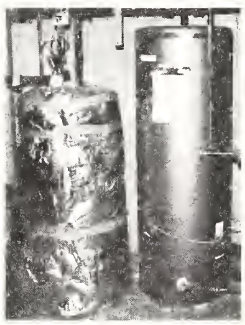
Recommendations: The team recommends that manufacturers and packagers provide pressure relief valves and that installers always include them with closed-loop systems. In recent installations, relief valves, when installed, were usually placed inside the home, often as part of the air purger assembly, where they can be vented to a safe location. This is good practice because antifreeze sometimes stains and damages roofing materials.

Temperature/pressure relief valves must be installed on all pressurized vessels. The manufacturer or packager has the responsibility to include these valves with systems.

Storage Tanks

The site evaluation team was surprised to find that 51 percent of the storage tanks examined were placed in what was considered an unheated area. In concert with inadequate insulation, this underscores a lack of understanding of standby losses by the solar industry. In certain isolated cases, rather remarkable placements were observed. A tank, for example, was buried in an uninsulated hole in a crawl space, making servicing all but impossible.

Of 159 reported cases, 70 percent had no on-site insulation added to the solar storage tank. HUD standards mandate a minimum of R-11 on storage tanks. The team inspectors felt that none of the tanks without additional insulation complied with this standard. Packagers and manufacturers do not encourage installers to add insulation when they paint the tanks special colors and place decals on them with information about the system.



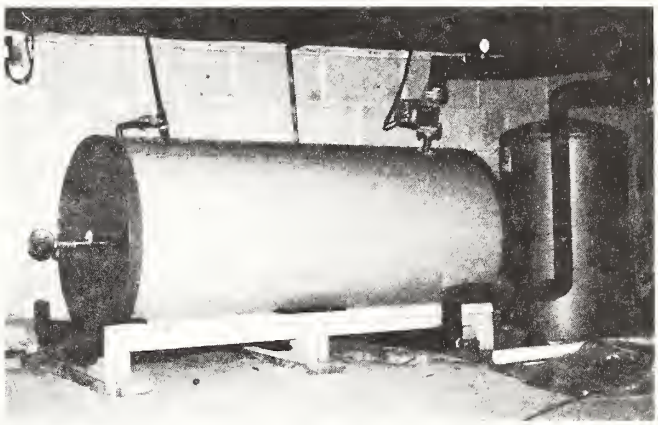
The solar tank in this domestic hot water system is properly insulated, and the wrapping is neat. The installer, however, failed to insulate the auxiliary tank.

Although some tanks were insulated on-site, most—though not all—of the work was sloppy. Some wraps looked leaky and unprofessional.

Nearly four out of five systems used the solar tank as a preheater to a second tank or to a tankless coil. A number would have benefited from a bypass interface. Most homeowners indicated that they try to keep the backup turned off during the summer. The most efficient way to do this with a double-tank system or a tankless coil is to bypass the second energy source altogether during times of favorable solar collection.

Recommendations: Manufacturers must be much more specific in their installation manuals about straightforward considerations such as tank placement. If tanks must be placed in unheated areas, insulation of R-20 minimum is strongly recommended. Tanks must be installed so that they can be serviced. Solar tank losses are known to be severe, often 4 million Btu a year, plus or minus, in an unheated location. Specially cut tank wraps and kits should be a common component of the solar hot water package.

The pitch of this roof is 23°. Snow fell five days before this picture was taken and still had not shed from the shallow-mounted collectors.



Horizontal placement of this stonelined storage tank is a mistake. The stone lining could fall, and the electrical heating element will not produce proper temperature stratification within the tank. Standby losses will be substantial because the tank is placed in an unheated area and has too little insulation.

Finally, the team recommends that installers become familiar with bypass techniques and use them more often. Homeowners seem ready and willing to deal with the valves and switches. The savings can be substantial.

Monitoring and Manuals

Systems that have no thermometers on the domestic water outlet of the storage tank afford the homeowner no opportunity to know whether the system is producing a meaningful amount of heat. More thermometers were installed by contractors on the loop than on the hot water outlet at the tank.

In nearly one-third of the cases studied, a system manual was not left with the homeowner. Several homeowners admitted to a total lack of knowledge about their systems.

Recommendations: For homeowner monitoring and for system diagnosis and service by the installer, three thermometers should be standard in all solar water heaters: one on the domestic water outlet as an overall measure of system operation, and two on the solar loop—one on the supply and the other on the return. Manufacturers should include the three thermometers as standard components. The team strongly urges manufacturers and packagers to supply manuals explaining the operation of their equipment. Installers should provide manuals to the consumer describing the proper use of the system.

Energy Division
Capitol Station
Helena, MT 59620

Montana Department of
Natural Resources and Conservation